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# Benchmark comparisons between the RESRAD and GENII dose assessment computer codes

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**Benchmark comparisons**  
**between the RESRAD and GENII dose assessment computer codes**

by

Adriana Rindiani

A Thesis Submitted to the  
Graduate Faculty in Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE

Department: Mechanical Engineering  
Major: Nuclear Engineering

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Signatures have been redacted for privacy

Signatures have been redacted for privacy

Iowa State University  
Ames, Iowa

1995

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## CHAPTER 1. INTRODUCTION

### Radioactive Waste

Nowadays, radioactive material is more widely used than ever. The demand for radioactive materials is continuing to increase. This demand requires that radioactive materials be processed from natural sources or reprocessed from irradiated materials. All of these processing steps result in the production of various forms of radioactive wastes. These radioactive wastes have different characteristics according to their chemical, physical, or radiologic properties.

Radioactive wastes are usually classified based on [9,11]:

1. The half life of the isotope, which classifies the radionuclide as short or long-lived;
2. The concentration of the radionuclides, which determines the classification level of the waste as low, medium, or high; and
3. The ability of the radioactive waste to generate heat, which is also dependent upon the concentration of the radionuclide.

Unlike any other waste, the handling of the radioactive waste poses unique challenges. To better control the handling of radioactive materials, the federal government has classified radioactive waste into several types, such as [11]:

1. High-level radioactive waste (HLRW) which includes spent nuclear fuel and the wastes produced in spent fuel reprocessing. This radioactive waste contains fission products and plutonium (Pu) isotopes. Because this waste is highly



radioactivity, it can generate significant quantities of heat. Since this class of waste requires massive shielding, it must be handled remotely.

2. Transuranic (TRU) waste results from weapons fabrication and spent reactor fuel reprocessing, and contains isotopes above uranium (U) in the periodic table. Compared to the HLRW, the TRU waste has less radioactivity and generates less heat. This waste still takes a long time to decay. The handling of this radioactive waste is similar to HLRW, but generally little or no shielding is required.

3. Low-level radioactive waste (LLRW) is all radioactive wastes other than those described in the previous two classifications. Almost all of the LLRW has low radioactivity and relatively short-lived radionuclides. This radioactive waste is usually produced from nuclear power production, industrial, institutional and government sources. Since these wastes generate little heat and have relatively low levels of radioactivity, little or no shielding is required.

The radioactive wastes, based on the above classifications, have to be handled very carefully due to their radiologic characteristics. The handling procedures are very different for every type of radioactive waste. For example, LLRW is buried in a shallow land burial site while HLRW is disposed in a deep geologic repository. When radioactive waste is stored, care must be taken to make sure that the container and the storage facility are properly designed for the class of radioactive waste to be disposed. During the storage of radioactive wastes, care must also be taken to monitor the potential release of radionuclides to the environment.

To predict the effects of such releases, special computer codes have been developed based on regulations from the federal government. These computer codes are used to calculate the release dose to the environment after a certain time

and to evaluate the radiation dose to individual organs or the whole body for an individual or population exposed by a release from the disposal site.

### **Role of Computer Codes in Radioactive Waste Management**

Computer codes are very important in the management of radioactive wastes since they can be employed to calculate a number of important parameters. These parameters include the release dose to the environment and the effective dose to the human body. A number of pathways must be considered in the development of a dose assessment computer code, such as [3,13]:

1. Direct or external exposure;
2. Inhalation pathway; and
3. Ingestion pathway.

In addition, there are also some transport mechanisms which have to be considered in order to calculate the committed dose to the human body. These transport mechanisms include radionuclide transport through the air, surface water, ground water, and biotic transport.

Two computer codes that have been developed to calculate the release dose on the environment near a LLRW disposal site are the GENII (GENeration II) and the RESRAD (RESidual RADionuclides) programs. The GENII program is used to calculate potential radiation doses to human from radionuclides in the environment. The RESRAD program is used to calculate radiation dose to an on-site resident using site-specific residual radioactivity guidelines.

By using these two computer codes, people can calculate the release dose from the same LLRW storage facility. However, the results will be different for each



calculation since each computer code employs a somewhat different approach. To permit a comparison between the RESRAD and GENII codes, the output of the RESRAD code must be modified using some of the formulas employed by the GENII program. This modification yields a release dose to specific organs of the human body, similar to the output of the GENII program.

### **Objective**

The primary objective of this research is to the development of an additional transport program module for the RESRAD code. This module will be derived from formulas employed in the GENII code to permit benchmark comparisons between these two codes. The results of this work may permit an evaluation of the conservatism of each code.

### **Outline of Thesis**

The first chapter of this thesis is the introduction, which includes a brief definition of radioactive waste and a description of the computer codes used in this research. This chapter also outlines the objective of the research. The second chapter is a literature review, which provides an overview of radiation and it's biological effects, LLRW, performance assessment (PA), regulations, and waste sites (WS). The third chapter discusses materials and methods. In the materials section, the GENII, RESRAD, and the transport program, and the scenario to be evaluated are discussed. In the methods section, the software employed is discussed, i.e., turbo PASCAL. In addition, the limitation in developing the transport program are discussed. The limitations include the dimensions, the pathway, and

the food transfer factors for each isotope. The fourth chapter will present the results of the transport program developed for this research effort and the comparison with the GENII program. The last chapter presents the conclusions. This chapter will summarize the results of this research, and make suggestions for future work. A program listing and sample results for each computation are presented in the appendices.

## CHAPTER 2. LITERATURE REVIEW

### Radiation and Its Biological Effects

Radioactivity is defined as spontaneous nuclear transformation that results in the formation of a new element [6]. The nuclear transformation can occur by alpha emission, beta emission, positron emission, gamma emission, or electron capture.

The activity of every radioactive material is unique. It depends on the instability of the nucleus, which results from either high or low neutron to proton ratio in accordance with the mass-energy relationship. Radioactivity does not depend on the chemical and physical properties of a material.

#### Radiation processes

**Alpha emission ( $\alpha$ )** An alpha particle, also known as helium ( ${}_2\text{He}^4$ ), is produced from a heavy nucleus with a low neutron to proton ratio. The alpha particle consists of two neutrons and two protons. When a radionuclide emits an alpha particle, it will reduce the atomic number by two and the atomic mass number by four. For example in  ${}_{92}\text{U}^{238}$ , the radioactive decay reaction is



The energy of this alpha particle is monoenergetic. The neutron to proton ratio of the parent is 1.58 to 1, while that for the daughter is 1.6 to 1. Alpha emission will occur several times until the nucleus reaches stability. The summation of all of these radioactive emissions is called a radioactive decay chain.

Since the linear energy transfer from an alpha particle to tissues is very large, the dead outer layer of skin is thick enough to prevent an alpha particle from penetrating the skin. Alpha decay does not result in any harm if the radiation source is external. If the radiation source is inside the body, the alpha particle will penetrate living tissue and can cause significant damage to an organ or to the entire organism.

**Beta emission ( $\beta^-$ )** A beta particle is a single negative electrical charge ejected from the nucleus of a beta-unstable radionuclide. This particle, which has characteristics identical to those of an electron, has a very small mass (0.00055 atomic mass units). Beta decay occurs over a continuous energy distribution.

A beta particle has the ability to penetrate into living tissue to varying depths depending upon the energy of the particle. Because of this ability, the beta particle can cause significant radiologic effects. To protect the body from this hazard, protective clothing designed to provide shielding should be worn when working with beta emitting materials.

**Positron emission ( $\beta^+$ )** A positron is a beta particle with positive charge. This particle has the same characteristics as beta particle. Therefore, the handling of positron emitting materials is the same as for the beta particle.

**Gamma emission ( $\gamma$ )** Gamma photons are electrically neutral and are emitted from nuclei of excited atoms. Some gamma emissions occur in conjunction with other radioactive decay processes. Gamma photons are also produced from annihilation of electron-positron pairs. The annihilation process usually occurs near an isotope that emits positrons. Gamma radiation usually requires significant shielding for radiation protection.

**Electron capture ( $e^-$ )** When a radioisotope cannot attain stability by positron emission, it can capture an orbital electron and convert a proton to a neutron. The process is known as K-shell capture since electrons in the K shell are much closer to the nucleus. The formation of a neutron by capturing an orbital electron can be described as follows:



A neutrino ( $\nu$ ) is always formed during electron capture. For energy to be conserved, this neutrino has an energy which is the difference between the actual kinetic energy and the observed kinetic energy of the system. Following the electron capture, low energy X-rays can also be produced. Therefore, shielding is also required for isotopes undergoing electron capture.



## Biological effects

Particles and photons resulting from radioactive decay can penetrate into a material and result in two different reactions: non-ionizing and ionizing reactions. Non-ionizing radiation includes photons originating from lasers, micro-waves, radio-waves, and light sources. This radiation does not cause any changes in atomic structure, but it can cause some superficial damage to living tissues, such as sunburn. Ionizing radiation, in the form of photons, such as gamma rays and X-rays, or particles, such as alpha, beta, and positron, can cause direct damage to living tissue. This ionizing radiation causes an electron to be ejected from the atom and leaves the atom with an electrical charge. This charged atom is called an ion.

Ionizing radiation can cause some biological effects. These effects are classified into three categories:

1. Somatic effects: These effects will affect the entire body. These are further classified into two effects: prompt somatic effects which can be observed as soon as the body receives a large or acute dose, and delayed somatic effects which occur years after receiving radiation exposure;
2. Genetic effects: These effects may occur in the offspring of exposed individuals; and
3. Teratogenic effects: These effects occur due to exposure to the unborn child during the fetal or embryonic stages of development.

**Radiation effects** Radiation effects can be classified into stochastic and non-stochastic effects (Figure 2.1). A stochastic effect occurs with the same probability for a control population, as well as to those exposed to radiation. Stochastic effects do not depend on the radiation exposure. In health physics, stochastic effects are divided into two classes: cancer and genetic effects. The probability of these effects occurring is independent of the magnitude of the dose.

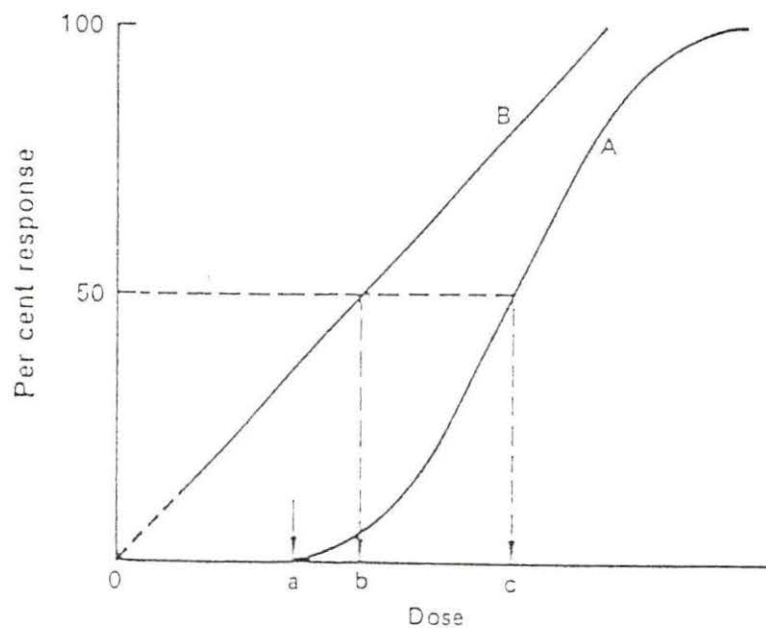


Figure 2.1 Non-stochastic (A) and stochastic (B) curves [6]

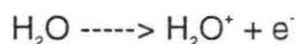
Non-stochastic effects are defined based on [2,11]:

- a. A certain minimum dose must be exceeded before the particular effect is observed;
- b. The magnitude of the effect increases with the size of the dose; and

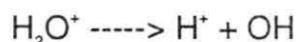
c. There is a clear causal relationship between exposure to the noxious agent and the observed effect.

**Direct action** A direct action includes radiation effects that can be seen when the tissue is irradiated. Genetic mutation is included in this category. An atom in the DNA molecule is changed by dissociating due to the ionization or excitation caused by the radiation. This change prevents the DNA from correctly conveying genetic information to the next generation. This action occurs in the somatic cells, which reproduce at relatively high rates.

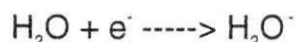
**Indirect action** A body consists primarily of water ( $H_2O$ ). Under irradiation conditions, the water in the body will be ionized as



The positive ion will dissociate into



and the electron will react with the water and produce



The negatively charged water will dissociate directly into



The free radicals,  $H$ , and  $OH$  in the body will react with a like radical or other molecules in solution. This reaction can create hydrogen peroxide ( $H_2O_2$ ) or hydroperoxyl radicals ( $HO_2$ ). Because of the toxicity of the molecules resulting from



this reaction, and since the body contains a lot of water, excessive exposure to these conditions can be extremely detrimental to the health of the irradiated organism. All of these processes take a long time and the effect occurs not only in the portions of the body exposed to radiation, but throughout the entire body.

**Acute effects** Whole body radiation exposure will affect the individual organs and all of the systems of the body. Since not all organs are sensitive to radiation, the effects which occur depend on the magnitude of the dose. The effects are classified into three syndromes [2,6]: hemopoietic, gastrointestinal, and central nervous system. All of these syndromes can be seen in the exposed population through the following symptoms [6]:

1. nausea and vomiting;
2. malaise and fatigue;
3. increased body temperature; and
4. blood composition changes.

**Delayed effects** These effects occur when a person receives a single large exposure or continual low-level exposure of radiation. Due to either one of these exposure scenarios, tissues will change slowly. The result of this effect can be seen as genetic mutation, cancer, or cataracts.

## Low-level Radioactive Waste (LLRW)

### Classification of radioactive waste

Radioactive waste is classified into three types according to its physical properties:

1. Gaseous waste: This waste is produced at reprocessing plants and nuclear power plants. The most common radionuclides in this waste are  $\text{Kr}^{85}$ ,  $\text{I}^{131}$ ,  $\text{C}^{14}$ , and  $\text{H}^3$ . The gaseous waste is usually captured and contained to permit radioactive decay or released to the environment in very small quantities.

2. Liquid waste: This waste is produced at spent fuel reprocessing plants. It comes from the chemical extraction of uranium and plutonium from spent fuel. Besides the spent fuel reprocessing plant, hospitals also generate liquid waste. The liquid waste must be solidified before it is shipped to a disposal site.

3. Solid waste: This waste results from the mining and milling of U and Th ores, from spent fuel, and from contaminated equipment. The solid waste is usually compacted or incinerated and placed in containers before it is shipped to a disposal site.

LLRW is produced in solid and liquid forms. It is generated from commercial nuclear fuel cycle operations, institutions such as hospitals and universities, industrial users, decontamination and decommissioning of fuel cycle facilities, and defense-related activities (Table 2.1).

Table 2.1 Nuclear waste types and sources [14]

Source	Nuclear waste types			
	Spent nuclear fuel (SNF)	High-level waste (HLW)	Transuranic waste (TRU)	Low-level waste (LLW)
Commercial nuclear fuel cycle operations	X	X		X
Institutions (hospitals, universities, etc.)	X		X	X
Industrial users	X		X	X
Decontamination and decommissioning of fuel cycle			X	X
Defense-related activities	X	X	X	X

### Classification of low-level radioactive waste

LLRW is classified into 3 classes due to its radionuclide concentration as shown in Table 2.2 and 2.3 [9,14]:

1. Class A wastes: Defined as having concentrations of specific radionuclide less than the value listed in Tables 1 and 2 of 10 CFR 61;
2. Class B wastes: Contain radionuclide concentrations greater than Class A but less than Class C, as defined in Table 2 of 10 CFR 61; and
3. Class C wastes: Contain radionuclide concentrations greater than Class B but less than column 3 of Table 2 of 10 CFR 61.

Table 2.2 Table 1 of 10 CFR 61 [14]

Radionuclide	Concentration (Ci/m <sup>3</sup> )
<sup>14</sup> C	8
<sup>14</sup> C in activated metal	80
<sup>59</sup> Ni in activated metal	220
<sup>44</sup> Nb in activated metal	0.2
<sup>99</sup> Tc	3
<sup>129</sup> I	0.08
Alpha-emitting transuranic nuclides with half-life greater than 5 years	100 <sup>a</sup>
<sup>241</sup> Pu	3,500 <sup>a</sup>
<sup>242</sup> Cm	20,000 <sup>a</sup>

<sup>a</sup>Units are nanocuries per gram.

Table 2.3 Table 2 of 10 CFR 61 [14]

Radionuclide	Concentration (Ci/m <sup>3</sup> )		
	Col. 1	Col. 2	Col. 3
All nuclides with less than 5-year half-life	700	<i>b</i>	<i>b</i>
<sup>3</sup> H	40	<i>b</i>	<i>b</i>
<sup>60</sup> Co	700	<i>b</i>	<i>b</i>
<sup>63</sup> Ni	3.5	70	700
<sup>63</sup> Ni in activated metal	3.5	700	7000
<sup>90</sup> Sr	0.04	150	7000
<sup>137</sup> Cs	1	44	4600

<sup>a</sup>No estimated limits.

## Sources of the LLRW

**LLRW from nuclear power reactors** LLRW is generated from all processes in the nuclear power plant that relate to the radioactive contamination of equipment, cooling water, clothing, plastics, construction material, ion exchange resins and filters, and sludge from water purification evaporators. Typical radionuclides produced in these processes are C<sup>14</sup>, Co<sup>60</sup>, Te<sup>99</sup>, Ni<sup>59</sup>, etc.

**LLRW from industries** Typical radionuclides produced in industrial applications are  $\text{Co}^{60}$ ,  $\text{C}^{14}$ ,  $\text{P}^{32}$ , and  $\text{I}^{125}$ . One significant source of these isotopes is radio-pharmaceutical development.

**LLRW from institutions** LLRW can be produced from the research conducted in hospitals or universities. In medical research, the most common radionuclides used are  $\text{H}^3$ ,  $\text{C}^{14}$ ,  $\text{P}^{32}$ , and  $\text{S}^{35}$ . Many of these radionuclides are usually used in developing or testing new prescription drugs. In other research (academic), these radionuclides can be used in soil analysis, reactor experiments, and materials testing.

### **Regulations Governing the Handling and Disposal of LLRW**

In 1980, the US Congress enacted the LLW Policy Act that urged all states to form compacts to handle the LLRW generated in their region [14]. This act also required that LLRW disposal became the responsibility of each state. The progress of forming the state compacts was so slow that in 1985, the Congress enacted the Low-Level Waste Policy Amendments Act (LLWPAA) which delayed the requirement for compact formation and new disposal site operation until 1993 (Table 2.4 and Figure 2.2).

In addition to these Acts, there are other federal regulations addressing the processing, storing, and shipping of LLRW. These regulations have been



promulgated by the US Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC). These regulations are part of the Code of Federal Regulations (CFR) under Title 49 for the DOT, Title 40 for the EPA, and Title 10 for the NRC.

### **DOT regulations**

The DOT regulations were written as Title 49 of the CFR. These regulations include general regulation for hazardous and radioactive materials and their transport (Table 2.5).

### **EPA regulation**

The EPA regulation relevant to LLRW handling is 40 CFR 190. This regulation addresses issues related to Nuclear Power Operation. This regulation also defines the classification of LLRW based on the activity of the radionuclides contained in the waste. An additional EPA regulation relevant to LLRW is 40 CFR 140, which sets the standards for clean drinking water. The maximum allowable radiation dose for drinking water is 4 mrem for the whole body.

Table 2.4 Interstate compacts based on the LLWPAA [14]

Southeast	Northwest	Midwest	Central	Rocky Mountain	Northeast	Central Midwest
Alabama	Alaska	Indiana	Arkansas	Colorado	Connecticut	Illinois
Florida	Hawaii	Iowa	Kansas	Nevada	New Jersey	Kentucky
Georgia	Idaho	Michigan	Louisiana	New Mexico		
Mississippi	Montana	Minnesota	Nebraska	Wyoming		
N. Carolina	Oregon	Missouri	Oklahoma			
S. Carolina	Utah	Ohio				
Tennessee	Washington	Wisconsin				
Virginia						

Table 2.5 Title 49, Transportation Subchapter C-Hazardous materials regulations  
[14]

49 CFR 171	General information, regulations, and definitions
49 CFR 172	Hazardous materials tables and hazardous materials communications regulations
49 CFR 173	Shippers—general requirements for shipments and packagings
49 CFR 174	Carriage by rail
49 CFR 175	Carriage by aircraft
49 CFR 176	Carriage by vessel
49 CFR 177	Carriage by public highway
49 CFR 178	Shipping container specifications
49 CFR 179	Specifications for tank cars

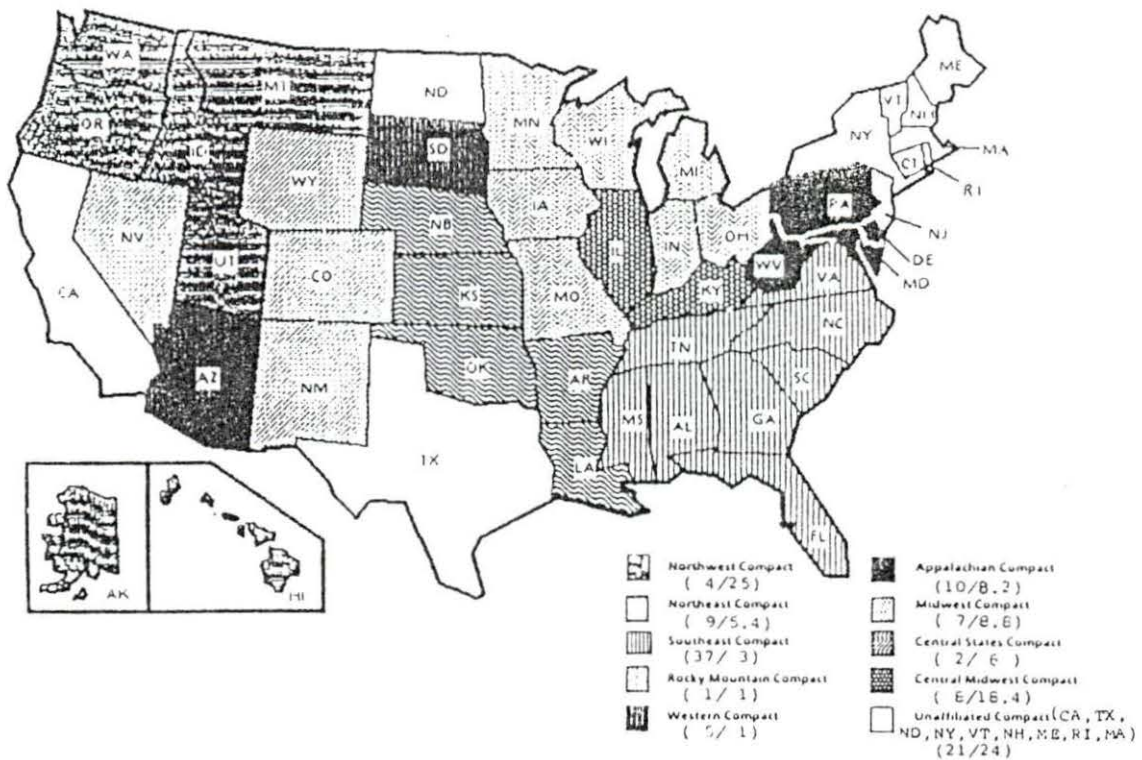


Figure 2.2 LLRW compacts as proposed on April 1987 [14]

## **NRC regulations**

The NRC regulations addressing LLRW include [14]:

1. 10 CFR 20 This regulation defines concentration limits on effluents.

Appendix B of this regulation limits the concentration of specific radionuclides in air and water;

2. 10 CFR 50 This regulation is used to set forth design objectives for equipment to control radioactivity in effluents;

3. 10 CFR 61 This regulation covers the licensing requirements for land disposal of low-level radioactive waste. Subpart C, Sections 61.41 and 61.42 regulates the requirements for LLRW disposal site performance as:

- a. Radioactivity released to the general environment in ground water, air, soil, plants and animals must not result in an annual dose exceeding an equivalent of 25 mrem for the whole body, 75 mrem in the thyroid, and 25 mrem for any other organ;

- b. Compliance with this regulation will be demonstrated with performance assessment calculations, including dose assessment;

4. 10 CFR 71 This regulation addresses all packaging, preparation for shipment, and transportation of radioactive materials, and provides the procedures and standards for NRC approval of packaging and shipping of radioactive materials.



## Performance Assessment Modeling

Performance assessment (PA) modeling is widely used in the evaluation of radioactive waste disposal sites. PA is used to calculate the long term behavior of the disposal facility based on certain pathways and transport mechanisms as a function of time (Figure 2.3 and 2.4). The PA methodology developed for each LLRW facility is employed to evaluate the potential impacts to the general public from the operation and post-closure performance of the LLRW disposal facility.

The PA analysis completed in this study is based on the disturbed or inadvertent intruder scenario, as described in 10 CFR 61. For this analysis, radionuclides are assumed to be released to the environment and the resulting doses are determined. This methodology can also be used to determine the dose to the maximally exposed individual from the most significant pathway.

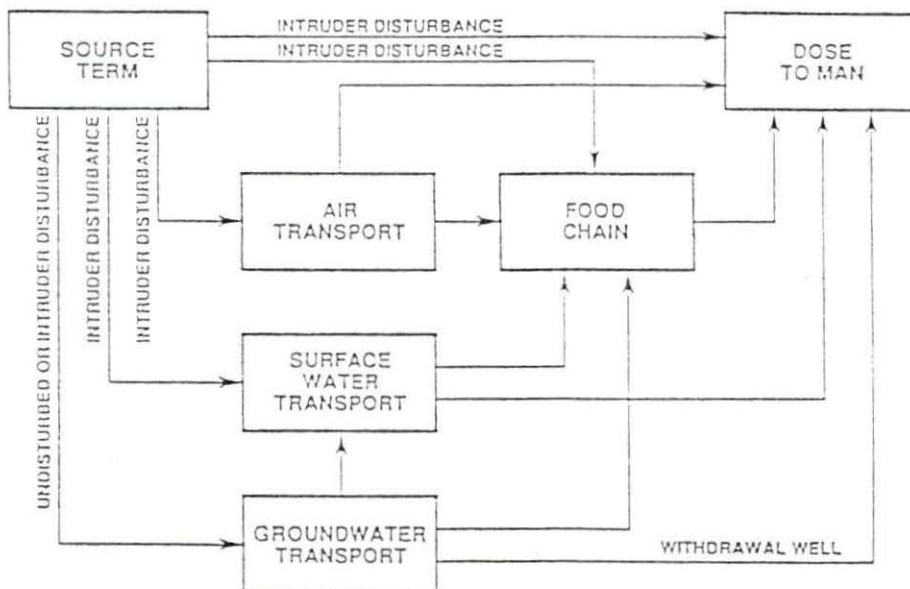


Figure 2.3 Pathways for undisturbed site [3,8]

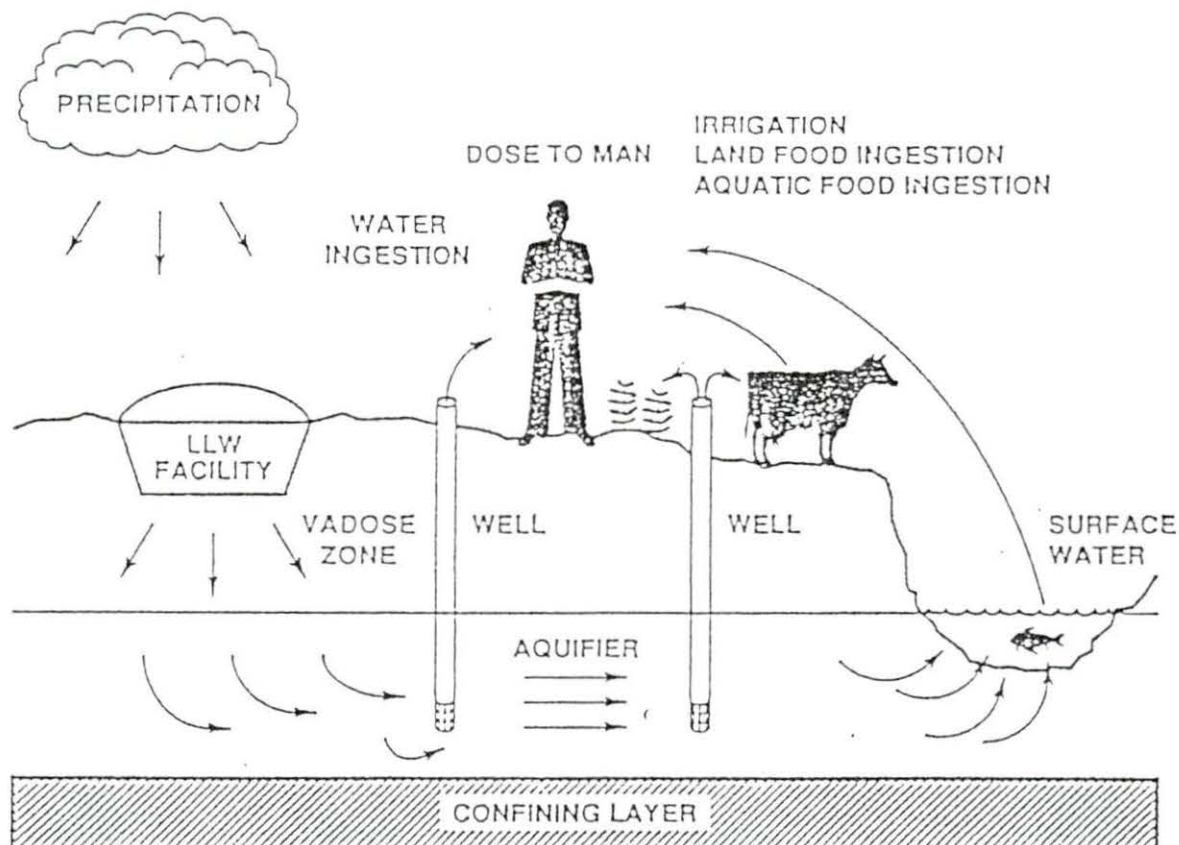


Figure 2.4 Transport pathways [3,8]

The pathways usually used in PA analysis are:

1. External exposure;
2. Inhalation; and
3. Ingestion that comes from drinking water and the food chain.

In using or developing a PA analysis model, the user must describe a scenario that will be modeled to determine the radionuclide release and the resulting dose to an exposed individual or population. This scenario development

must address many issues, such as [12] identifying the source term for the radionuclide inventory, calculating the release rate of each radionuclide, calculating the transport of each radionuclide to the accessible environment, and determining the dose to the general public.

### **Waste Sites**

As a result of the LLWPAA, the US is divided into 9 compacts: Southeast, Northwest, Midwest, Central, Rocky Mountain, Northeast, Central Midwest, Appalachian, and Western. These compacts have the responsibility to dispose of radioactive waste generated by the member states in a disposal site located in a designated host state. 10 CFR 61 provides some requirements to be met during construction and operation of a near-surface disposal facility.

The near surface disposal facility is defined as the terminal emplacement site for radioactive wastes. These facilities are constructed on or near the earth's surface [10]. Because the position of the waste is on or near to the earth's surface (maximum depth is 30 meters), this waste site will be subjected to natural process such as erosion, flooding, plant and animal intrusion, etc. LLRW sites are built to contain only radioactive waste with relatively low concentration of radionuclides a majority of which usually exhibit short half-lives.

Near-surface disposal facilities can be classified into several types [10]. The first technology employed for LLRW disposal was shallow land burial. In these

sites, the radioactive waste is placed in metal drums and concrete containers and is covered with one to three meters of soil or clay. Existing shallow land burial sites release relatively low radiation doses to the environment. Although this method is the least expensive among all methods for LLRW disposal, it has been outlawed in a majority of the new Compact host states.

The second method employs engineered structures in the form of vaults, which are placed above-ground or below-ground. The third method utilizes rock cavities or dry abandoned mines. The radioactive waste is emplaced in the bedrock, which is usually about 100 meters from the earth's surface. The final LLRW disposal method, which was initially employed to dispose liquid wastes, employed excavated basins and rock-filled trenches to serve as seepage basins. These basins were supposedly designed to limit the migration of liquid wastes until such time that a majority of the radionuclides had decayed. This technology, which was employed at a number of U. S. nuclear weapons fabrication facilities, is no longer utilized since it was rarely successful in adequately containing the liquid wastes.



## CHAPTER 3. MATERIALS AND METHODS

### Materials

#### The GENII code

The GENII code was first developed by B. Napier at the Pacific Northwest Laboratory (PNL) in 1988. This code is currently used to calculate radiation doses from radionuclides released to the environment. The code was designed to complete the following tasks [13]:

1. To calculate radiation doses for acute releases, with options for annual dose, committed dose, and accumulated dose;
2. To calculate radiation doses for chronic releases, with the same options as above; and
3. To evaluate exposure pathways including direct exposure via water, soil, air, inhalation pathways, and ingestion pathways.

The GENII code was developed based on the methods recommended in the International Commission of Radiation Protection (ICRP) Publications No. 26 (1977) and No. 30 and their supplements (1979-1982). The code was then further adapted by Sandia National Laboratory (SNL) by incorporating the SUNS software shell to

provide a workable personal computer interface and to permit stochastic evaluations. This new version of the code is known as GENII-S.

The GENII/GENII-S code is employed to evaluate various scenarios relevant to LLRW disposal including site-specific environmental conditions. The scenarios used are [12]:

1. Acute releases to air or water from ground level or elevated sources;
2. Chronic release to air or water from ground level or elevated sources; and
3. Initial contamination of soil or surfaces.

The evaluation of these scenarios with the GENII/GENII-S code permits the estimation of radiation doses to individuals or populations. The calculations can include the annual dose, dose commitments, or accumulated doses to the whole body or individual organs due to acute or chronic releases of radioactive materials.

The GENII/GENII-S code consists of seven linked computer codes and their associated data libraries (Figure 3.1). The first linked computer code is APPRENTICE which is used as a user interface to construct the input files for the GENII. The second code is ENVIN, which is used to setup the input. The third is ENV, which is used to calculate the environmental dose. EXTDF is then used to calculate the external dose factors. The DOSE program is used in dosimetry calculations yielding the total dose. The INTDF routine is used to calculate the

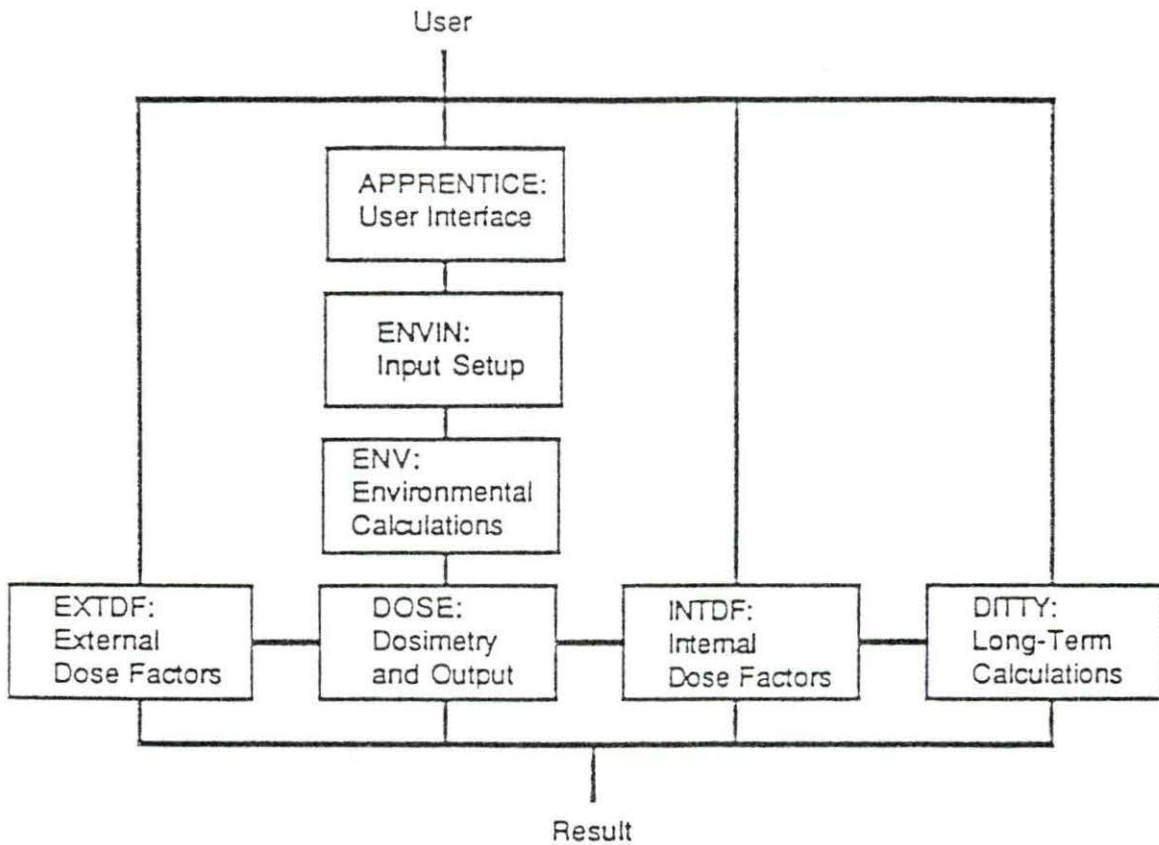


Figure 3.1 Current user/computer program interaction in the GENII Software Package [13]

internal dose factors. The final code is DITTY, which is used for long-term calculations. These seven computer codes are linked to provide dose calculation capabilities for a variety of exposure pathways and dose commitment scenarios.

The GENII/GENII-S code has a pull-down menu input format for construction of the input files. In order to operate this code, the user must understand the basic concepts associated with each scenario under consideration to permit identification of relevant input parameters. The input parameters employed are based on the

scenario. These parameters are selected to model a pattern of human activity corresponding to actions, events, and processes that result in radiation exposure to individuals or groups [12]. A scenario can be either a far-field or a near-field scenario. A far-field scenario is used to determine the effect of the potential radionuclide release to a wide environment, i.e., to individuals or populations. A near-field scenario is employed to determine the effect of the potential radionuclide release to an individual as a result of initial contamination. These two scenarios will include a number of parameters, such as chronic or acute atmospheric releases and chronic or acute surface water releases for a far-field scenario, and initial surface or subsurface soil contamination, groundwater contamination and cumulative effects for a near-field scenario.

Besides these scenarios, the user must also select the relevant transport mechanisms and exposure pathways employed. Transport mechanisms are defined as the way the radionuclide is released into the environment and travels to the exposed population. These mechanisms can occur through air, surface water, ground water and biotic transport. Exposure pathways are the potential routes through which the radionuclide comes in contact with an individual or population group, such as external exposure, ingestion, and inhalation.

The output of the GENII/GENII-S code is a series of dose calculations that estimate the internal effective dose equivalents (IEDEs), external doses, and total effective dose equivalents (TEDEs). The IEDEs can be either committed effective



dose equivalents or cumulative effective dose equivalents. The committed effective dose equivalent represents the doses from individual radionuclides to an individual or population in a one-year period after an intake (ingestion and inhalation). A cumulative effective dose equivalent is a dose expected for an individual or population after more than a one-year period of intake.

### **The RESRAD code**

The RESRAD code was developed by the Argonne National Laboratory (ANL) in 1980s. This code has been adapted to operate on IBM Compatible personal computers. The code is used to determine the potential radiation dose to an on-site resident using site-specific residual radioactive guidelines. A guideline is defined as a radionuclide concentration or a level of radiation or radioactivity that, given appropriate use scenarios and site parameters, will reasonably ensure that individual dose limits and/or constraints will be achieved [8]. The guidelines include concentrations of residual radionuclides in soil, concentration of airborne radon decay products, concentrations of residual radionuclides in air and water, levels of external gamma radiation, and levels of radioactivity from surface contamination [8]. According to the soil guidelines, concentration of Ra-226, Ra-228, Th-230, and Th-232 must be less than 5 pCi/g for the first 15 cm below the soil surface, and less than 15 pCi/g for each additional 15 cm for a specific site to meet the RESRAD dose limits. The concentration of other radionuclides can then be derived using the RESRAD code.

This code can also be employed on the shallow land burial sites. The exposure pathways used in the RESRAD code usually include [8]:

1. Direct exposure to external radiation from the contaminated soil materials;
2. Internal dose from inhalation of airborne radionuclides, including radon progeny; and
3. Internal dose from ingestion of plant foods grown in the contaminated soil and irrigated with contaminated water, meat and milk from livestock fed with contaminated fodder and water, drinking water from a contaminated well or pond, fish from a contaminated pond, and contaminated soil ingestion.

These pathways are evaluated in a manner similar to pathways used in the GENII/GENII-S code. One limitation of the RESRAD code when compared to the GENII/GENII-S code, is that the RESRAD code does not employ any transport mechanism. This limitation makes the evaluation of radiation doses to specific organs impossible. Hence, it was necessary to develop a transport program for RESRAD.

### **The transport program for the RESRAD code**

Since the GENII/GENII-S and the RESRAD codes are basically operated in a similar manner, it was determined that the RESRAD code could be modified to calculate the radiation dose to specific organs. In order to provide results which are compatible to the GENII/GENII-S results, a transport program for the RESRAD code

was developed. This program employs transport formulas similar to those used in the GENII/GENII-S program. This new program permits a direct comparison between the results from the RESRAD and GENII/GENII-S codes.

The formulas used in this study are based on the ingestion pathway. The results yield the committed dose equivalent on bone surfaces and in the kidneys. Based on GENII/GENII-S, the transport formulas for this pathway are [13]:

$$I = U * C_p(t=T_h) * \{1 - \exp(-\lambda_r * T_r)\} / \lambda_r$$

where,

$I$  : the total activity of a radionuclide ingested over a consumption period,  $T_r$  (pCi)

$U$  : the average ingestion rate of the crop over the ingestion period (kg/year)

$\lambda_r$  : the radiological decay constant (year<sup>-1</sup>)

$$= 0.693 / T_r$$

$T_r$  : the biologic half-life of the radionuclide in the target organ (year), which is

300 days for the bone surface and 15 days in the kidneys for  $U^{235}$  and  $U^{238}$

$T_f$  : the duration of the uptake period (year)

$C_p(t=T_h)$  : the radionuclide concentration in the plant at harvest time (pCi/kg)

and  $C_p(t=T_h)$  is calculated from :

$$C_p(t=T_h) = C_p(t=0) * \exp(-\lambda_e * T_h)$$

where,

$C_p(t=0)$  : the initial concentration of the radionuclide in the plant (pCi/kg)

$$= r * C_s(t=0) * Tv_p / Y_p$$

$C_s(t=0)$  : the initial soil surface concentration (i.e., at time  $t=0$ ) (pCi/m<sup>3</sup>)

$r$  : fraction of initial deposition retained on the plant (dimensionless)

$Tv_p$  : translocation factor from plant surfaces to edible parts of the plant (dimensionless), currently assumed at 1.0 for leafy vegetables and forage crops, and 0.1 for all other vegetation

$Y_p$  : yield of crop type  $p$  (kg/m<sup>3</sup>)

$\lambda_e$  : an effective removal constant (year<sup>-1</sup>)

$$= \lambda_r + \lambda_w$$

$\lambda_w$  : the weathering removal rate, based on a half time of 14 days (year<sup>-1</sup>)

$$= 0.693 / (14 / 365) = 18.0675 \text{ year}^{-1}$$

$T_h$  : the harvest time (year)

Finally, the committed dose equivalent (CDE) is:

$$CDE = 3.7 * 10^3 * \text{CDE per unit activity} * I \text{ (mrem)}$$

where CDE per unit activity is a committed dose equivalent in target organs or tissues per intake of unit activity (Sv/Bq). Tabular data of CDE's for various radionuclides can be found in supplements of ICRP Publication No. 30 (1979-1982).



## **Scenario**

The scenario evaluated with the GENII/GENII-S code and the RESRAD code with the additional transport program is the same. This scenario represents a low-level radioactive waste disposal site of the shallow land burial type. This is a near-field scenario with chronic release of the radionuclides U-235 and U-238. The pathway used is ingestion of leafy vegetables, other vegetables, cereals/grains, and fruits. The dose calculated is a committed dose equivalent on the surface bone and in the kidneys for an individual.

## **Methods**

### **The Turbo Pascal transport program**

The Turbo Pascal computer language was used in the development of the transport program. This language contains a program heading which is used to name the program and the main program block which completes the calculation. The main program block is written between two keywords: begin and end.

The transport program was written using in Turbo Pascal and employed the results of the RESRAD program as input parameters. A calculation of the transport of each radionuclide to each target organ was the completed. The results of these calculations yielded the organ-specific dose for each isotope. These results can be directly compared to the GENII/GENII-S results.



## Limitations

Calculations of this type can be extremely difficult when a number of radionuclides and pathways are considered. To simplify this task, the transport program was written to calculate only the committed dose equivalent for  ${}_{92}\text{U}^{235}$  and  ${}_{92}\text{U}^{238}$  on the bone surface and kidneys from the ingestion of leafy vegetables, all other vegetables, cereal/grains, and fruits. Having demonstrated the methodology, similar transport programs may be easily developed for other radionuclides and pathways.

The dimensions used as the input of the GENII and RESRAD codes are pCi/m<sup>3</sup> and pCi/g, respectively. For the transport program, the input parameter dimension is pCi/m<sup>3</sup>. The dimensions of the output of the GENII code and the transport program are rem and mrem, respectively.

## CHAPTER 4. RESULTS

The committed effective dose equivalents (CEDE) for the bone surface and kidneys for a one year exposure and one year dose commitment of  ${}_{92}\text{U}^{235}$  and  ${}_{92}\text{U}^{238}$  are presented in Table 4.1 and 4.2 for the GENII code and the transport code developed in this research, respectively.

Table 4.1 The results from the GENII code

Radionuclide	Bone Surface (mrem)	Kidneys (mrem)
U - 235	$5.9 \cdot 10^{-11}$	$1.6 \cdot 10^{-10}$
U - 238	$5.8 \cdot 10^{-11}$	$1.5 \cdot 10^{-10}$

Table 4.2 The results from the transport program

Radionuclide	Bone Surface (mrem)	Kidneys (mrem)
U - 235	$9.19 \cdot 10^{-5}$	$6.68 \cdot 10^{-8}$
U - 238	$9.19 \cdot 10^{-5}$	$6.37 \cdot 10^{-8}$

The results presented in these tables suggest that there is limited agreement for the dose to the kidneys calculated by the GENII/GENII-S code and the transport code developed in this research effort. There is relatively poor agreement for the bone surface doses. These differences may be due to:

1. The initial concentration for the GENII code is in units of pCi/m<sup>3</sup>. For the RESRAD code, the initial concentration is in units of pCi/g. The initial concentration for the RESRAD code was calculated by assuming that the concentration can be related by the density of the waste disposal material, i.e., assume that the contaminated materials and soils have the same bulk density ( $2.4 \times 10^6$  g/m<sup>3</sup>). So, the calculation for the initial concentration for the RESRAD code becomes:

$$IC(RESRAD) = IC(GENII) / \rho_b$$

where,

IC(RESRAD) : the initial concentration for the RESRAD input (pCi/g)

IC(GENII) : the initial concentration for the GENII input (pCi/m<sup>3</sup>)

$\rho_b$  : the bulk density (g/m<sup>3</sup>)

2. For the transport program, again the initial soil concentration is required. The initial soil concentration is taken from an output file of RESRAD, named CONCENT.REP, for the time period desired. Here again, the units must be changed. For this parameter, the soil density ( $1.6 \times 10^6$  g/m<sup>3</sup>) is used to convert from pCi/g to pCi/m<sup>3</sup>. The equation for this concentration is

$$IC(ADD) = IC(OUTPUT) * \rho_s$$

where,

IC(ADD) : the initial soil surface concentration (pCi/m<sup>3</sup>)

IC(OUTPUT) : the initial soil surface concentration from the RESRAD output  
(pCi/g)

$\rho_s$  : the soil surface density ( $\text{g/m}^3$ )

3. The formula used in the transport program is most likely too simplistic since it ignores several factors, such as food transfer factors (FTF), which are different for every radionuclide. In the GENII code, this factor is tabulated in FTRANS.DAT, which contains transfer factors relating concentrations of elements in soil to concentrations in farm products grown in that soil, and relating concentrations in animal feed to concentrations in animal products [12]. For all kinds of farm products, the FTFs vary from  $10^1$  to  $10^4$ . Proper incorporation of this parameter in the transport program should improve the results of these calculations. These improvements may yield results similar to those given by the GENII code.

## CHAPTER 5. CONCLUSIONS

A benchmark comparison of the outputs of the GENII code and the RESRAD code modified with a transport program has been completed. The results of these calculations suggest limited agreement for an exposure of  $_{92}\text{U}^{235}$  and  $_{92}\text{U}^{238}$  to the kidneys. Poor agreement was attained for similar calculations completed for exposure of the same uranium isotopes to the surface of bones. One significant factor that may explain the discrepancies between these calculations is the omission of relevant food transfer factors for these isotopes in the RESRAD code which was modified with the transport program developed in this research effort.

Future work in this area should address:

1. Additional radionuclides;
2. Additional exposure pathways;
3. Additional target organs; and
4. Incorporation of relevant food transfer factors.



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## **APPENDIX A**

### **THE TRANSPORT PROGRAM AND ITS OUTPUT**

### Program List for the Transport Program

Program Additional\_Program\_for\_Resrad;

{N+}  
uses crt;

Var

Result,n,m	: integer;
organ1,organ2	: string[50];
lambda_w,Th,Cst0,Tf	: real;
CDE_bone,CDE_kidney,CDE235_bone,CDE235_kidney,	
CDE238_bone,CDE238_kidney	: array [1..2] of real;
Tot_Upt,Cpt0	: real;
r,Y,Tvp,Uptake	: array [1..4] of real;
T_half_bone,T_half_kidney,lambda_bone,lambda_kidney,lambda_e_bone,	
lambda_e_kidney,CpTh_bone,CpTh_kidney,Intake_bone,Intake_kidney,	
organ	: array [1..2] of real;
T,j,k	: integer;
filevar	: text;

Procedure Initialization;

Begin

for k := 1 to 4 do		
begin		
r[k]	:= 0;	(*dimensionless*)
Y[k]	:= 0;	(*unit in kg/m3*)
Tvp[k]	:= 0;	(*dimensionless*)
Uptake[k]	:= 0;	(*unit in kg/yr*)
end;		
for k := 1 to 2 do		
begin		
T_half_bone[k]	:= 0;	(*unit in years*)
T_half_kidney[k]	:= 0;	(*unit in years*)
lambda_bone[k]	:= 0;	(*unit in year-1*)
lambda_kidney[k]	:= 0;	(*unit in year-1*)
lambda_e_bone[k]	:= 0;	(*unit in year-1*)
lambda_e_kidney[k]	:= 0;	(*unit in year-1*)
Cpth_bone[k]	:= 0;	(*unit in pCi/m3*)
Cpth_kidney[k]	:= 0;	(*unit in pCi/m3*)



```

        Intake_bone[k]           := 0;           (*unit in pCi*)
        Intake_kidney[k]        := 0;           (*unit in pCi*)
        organ[k]                := 0;           (*target organ*)
    end;
End;

Procedure Dose_Calculation_on_Target_Organs_for_Ingestion_Pathway;

Begin
    assign(filevar,'c:\rindi\program\input.dat');
    reset(filevar);
    readln(filevar,m);
    for k := 1 to m do
        begin
            readln(filevar,r[k],Uptake[k],Y[k],Tvp[k]);
        end;
    close(filevar);
    Cpt0                               := 0;           (*units in pCi/kg*)
    Tot_Upt                           := 0;           (*units in kg/yr*)
    for k := 1 to m do
        begin
            Cpt0                       := Cpt0 + (Cst0 * r[k] * Tvp[k] / Y[k]);
            Tot_Upt                     := Tot_Upt + Uptake[k];
        end;
    assign(filevar,'c:\rindi\program\organ.dat');
    reset(filevar);
    readln(filevar,n);
    for j := 1 to n do
        begin
            readln(filevar,organ[j],T_half_bone[j],T_half_kidney[j],
            CDE_bone[j],CDE_kidney[j]);
            lambda_bone[j]             := 0.693 / T_half_bone[j];
                                         (*units in year-1*)
            lambda_kidney[j]           := 0.693 / T_half_kidney[j];
                                         (*units in year-1*)
            lambda_e_bone[j]           := lambda_w + lambda_bone[j];
                                         (*units in year-1*)
            lambda_e_kidney[j]         := lambda_w + lambda_kidney[j];
                                         (*units in year-1*)
            CpTh_bone[j]               := Cpt0 * exp(-lambda_e_bone[j]*Th);
                                         (*units in pCi/kg*)
            CpTh_kidney[j]             := Cpt0 * exp(-lambda_e_kidney[j]*Th);
                                         (*units in pCi/kg*)
        end;
    end;
End;

```

```

Intake_bone[j]      := Tot_Upt * CpTh_bone[j] *
                    (1 - exp(-lambda_bone[j] * Tf)) /
                    lambda_bone[j]; (*units in pCi*)
Intake_kidney[j]    := Tot_Upt * CpTh_kidney[j] *
                    (1 - exp(-lambda_kidney[j] * Tf)) /
                    lambda_kidney[j]; (*units in pCi*)

if organ[j] = 1 then
  begin
    CDE235_bone[j]   := 3.7E+3 * Intake_bone[j] *
                      CDE_bone[j]; (*units in mrem*)
    CDE235_kidney[j] := 3.7E+3 * Intake_kidney[j] *
                      CDE_kidney[j]; (*units in mrem*)
  end;

if organ[j] = 2 then
  begin
    CDE238_bone[j]   := 3.7E+3 * Intake_bone[j] *
                      CDE_bone[j]; (*units in mrem*)
    CDE238_kidney[j] := 3.7E+3 * Intake_kidney[j] *
                      CDE_kidney[j]; (*units in mrem*)
  end;
end;
close(filevar);
End;

Procedure Saving_to_disk;

Var
  filevar : text;

Begin
  assign(filevar,'c:\rindi\program\cde.out');
  rewrite(filevar);
  writeln(filevar,'Initial Soil Surface Concentration in pCi/m3 = ',Cst0);
  writeln(filevar,'Length of the Uptake Period in years      = ',Tf);
  writeln(filevar);
  writeln(filevar);
  writeln('Committed Dose Equivalent (mrem)');
  writeln('=====');
  writeln;
  writeln('U-235 : ');
  if Result = 1 then
    begin

```

```

    write(organ1);
    write(CDE235_bone[1]);
    writeln;
    write(organ2);
    write(CDE235_kidney[1]);
    writeln;
    result := 2;
end;
writeln;
writeln('U-238 : ');
if Result = 2 then
begin
    write(organ1);
    write(CDE238_bone[2]);
    writeln;
    write(organ2);
    write(CDE238_kidney[2]);
    result := 1;
end;
writeln(filevar,'Committed Dose Equivalent (mrem)');
writeln(filevar,'=====');
writeln(filevar);
writeln(filevar,'U-235 : ');
if Result = 1 then
begin
    write(filevar,organ1);
    write(filevar,CDE235_bone[1]);
    writeln(filevar);
    write(filevar,organ2);
    write(filevar,CDE235_kidney[1]);
    writeln(filevar);
    result := 2;
end;
writeln(filevar);
writeln(filevar,'U-238 : ');
if Result = 2 then
begin
    write(filevar,organ1);
    write(filevar,CDE238_bone[2]);
    writeln(filevar);
    write(filevar,organ2);
    write(filevar,CDE238_kidney[2]);
end;

```

```

    close(filevar);
End;

Begin
    Initialization;
    n                := 0;
    m                := 0;
    Result           := 1;
    clrscr;
    organ1           := 'Bone Surface = ';
    organ2           := 'Kidneys    = ';
    lambda_w         := 18.0675; (*units in year-1*)
    Th               := 0.2466;  (*units in years*)
    write('Initial Soil Surface Concentration in pCi/m3 = ');
    read (Cst0);      (*initial soil surface concentration in pCi/m3*)
    writeln;
    write('Length of the Uptake Period in years = ');
    read (Tf);        (*length of uptake period in years*)
    writeln;
    Dose_Calculation_on_Target_Organs_for_Ingestion_Pathway;
    Saving_to_disk;
    writeln;
    writeln;
    writeln('Please press any key to continue !!!!!!!');
    repeat until keypressed;
End.

```

C:\RINDI\PROGRAM\INPUT.DAT

```

4
2.0    15    1.5    1.0
4.0    140   4.0    0.1
2.0    64    2.0    1.0
0.6    80    0.8    1.0

```

C:\RINDI\PROGRAM\ORGAN.DAT

```

2
1      0.8219    0.0411    1.0E-6    4.3E-7
2      0.8219    0.0411    1.0E-6    4.1E-7

```

These two files are from the GENII manual and the ICRP Publication No. 30 (1979-1982). The original data are as follow:

Table A.1 Factors used for all kinds of vegetation

	r	Uptake (kg/yr)	Yield (kg/m <sup>3</sup> )	Translocation factor
Leafy veg.	2.0	15	1.5	1.0
Oth. veg.	4.0	140	4.0	0.1
Fruit	2.0	64	2.0	1.0
Cereals	0.6	72	0.8	1.0



Table A.2 Data for U-235 and U-238

	$T_{1/2}$ (year)	Organ	CDE/unit activity (Sv/Bq)
U - 235	0.8219	Bone Surface	1.0 E-6
	0.0411	Kidneys	4.3 E-7
U - 238	0.8219	Bone Surface	1.0 E-6
	0.0411	Kidneys	4.1 E-7

C:\RINDI\PROGRAM\CDE.OUT

Initial Soil Surface Concentration in pCi/m<sup>3</sup> = 4.2080000000E-03  
Length of the Uptake Period in years = 1.0000000000E+00

Committed Dose Equivalent (mrem)

=====

U-235 :

Bone Surface	= 9.1933561194E-05
Kidneys	= 6.6812501518E-08

U-238 :

Bone Surface	= 9.1933561194E-05
Kidneys	= 6.3704943308E-08

## **APPENDIX B**

### **THE GENII OUTPUT**

-----  
 GENII Dose Calculation Program  
 (Version 1.485 3-Dec-90)  
 -----

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:36

Page A. 1

-----  
 This is a near field (narrowly-focused, single site) scenario.  
 Release is chronic  
 Individual dose  
 -----

THE FOLLOWING TRANSPORT MODES ARE CONSIDERED  
 Biotic Transport  
 Waste Form Degradation

THE FOLLOWING EXPOSURE PATHS ARE CONSIDERED:  
 Terrestrial foods ingestion

THE FOLLOWING TIMES ARE USED:  
 Intake ends after (yr): 1.0  
 Dose calculations ends after (yr): 1.0

===== FILENAMES AND TITLES OF FILES/LIBRARIES USED =====

Input file name: \GENII\result.in  
 GENII Default Parameter Values (28-Mar-90 RAP)  
 Radionuclide Master Library (11/28/90 RAP)  
 Food Transfer Factor Library - (RAP 29-Aug-88) (UPDATED LEACHING FA  
 External Dose Factors for GENII in person Sv/yr per Bq/n (8-May-90 R  
 Internal Dose Increments, PNL Solubility Choices Rerun 12/3/90 PDR

=====

-----Release Terms-----

Release	Surface Buried		
Radio-	Air	Water	Source
nuclide	pCi/yr	pCi/yr	pCi/m3
U 235	0.0E+00	0.0E+00	1.0E+00
U 238	0.0E+00	0.0E+00	1.0E+00

===== NEAR-FIELD PARAMETERS =====

0.0 Inventory disposed n years prior to beginning of intake period  
 0 LOIC occurred n years prior to beginning of intake period  
 1.0E+00 Fraction of roots in upper soil (top 15 cm)  
 0.0E+00 Fraction of roots in deep soil  
 0.0E+00 Manual redistribution: deep soil/surface soil dilution factor

===== WASTE FORM AVAILABILITY =====

5.0E-01 Waste form/package half life, yr  
 1.5E-01 Thickness of buried waste, m  
 1.5E-01 Depth of soil overburden, m

===== BIOTIC TRANSPORT OF BURIED SOURCE =====

1 Pre-Intake conditions: 1-Arid Non Ag, 2-Humid Non Ag 3-Agriculture

===== TERRESTRIAL FOOD INGESTION =====

FOOD TYPE	GROW	--IRRIGATION--		YIELD kg/m2	PROD-	--CONSUMPTION--	
	TIME d	S RATE * in/yr	TIME mo/yr		DUCTION kg/yr	HOLDUP d	RATE kg/yr
Leaf Veg	90.0	0	0.0	0.0	1.5	14.0	1.5E+01
Oth. Veg	90.0	0	0.0	0.0	4.0	14.0	1.4E+02
Fruit	90.0	0	0.0	0.0	2.0	14.0	6.4E+01
Cereals	90.0	0	0.0	0.0	0.8	180.0	7.2E+01

Input prepared by: \_\_\_\_\_ Date: \_\_\_\_\_

Input checked by: \_\_\_\_\_ Date: \_\_\_\_\_



-----  
 GENII Dose Calculation Program  
 (Version 1.485 3-Dec-90)  
 -----

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48

Page C. 1

Release period: 0.0  
 Uptake/exposure period: 1.0  
 Dose commitment period: 1.0  
 Dose units: Rem

Organ	Committed Dose Equivalent	Weighting Factors	Weighted Dose Equivalent
Gonads	6.7E-15	2.5E-01	1.7E-15
Breast	2.3E-15	1.5E-01	3.5E-16
R Marrow	1.1E-14	1.2E-01	1.3E-15
Lung	1.9E-15	1.2E-01	2.3E-16
Thyroid	1.9E-15	3.0E-02	5.7E-17
Bone Sur	1.2E-13	3.0E-02	3.6E-15
LL Int.	2.3E-12	6.0E-02	1.4E-13
UL Int.	7.7E-13	6.0E-02	4.6E-14
Kidneys	3.1E-13	6.0E-02	1.9E-14
S Int.	1.4E-13	6.0E-02	8.1E-15
Stomach	5.3E-14	6.0E-02	3.2E-15
Internal Effective Dose Equivalent			2.2E-13
External Dose			0.0E+00
Annual Effective Dose Equivalent			2.2E-13

-----  
 Controlling Organ: LL Int.  
 Controlling Pathway: Ing  
 Controlling Radionuclide: U 235  
 -----  
 Total Inhalation EDE: 0.0E+00  
 Total Ingestion EDE: 2.2E-13  
 -----

---

GENII Dose Calculation Program  
(Version 1.485 3-Dec-90)

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Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48

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Release period: 0.0  
 Uptake/exposure period: 1.0  
 Dose commitment period: 1.0  
 Dose units: Rem

		Dose Commitment Year				
		1	2	3	...	
Internal :						
Intake :						
Year: 3				0.0E+00	...	
				+		
2		0.0E+00	0.0E+00	0.0E+00	...	Internal
		+	+	+		Effective
1		2.2E-13 + 0.0E+00 + 0.0E+00 + ...	=	2.2E-13		Dose
						Equivalent
Internal						Cumulative
Annual		2.2E-13 + 0.0E+00 + 0.0E+00 + ...	=	2.2E-13		Internal
Dose						Dose
		+	+	+	-	
External						
Annual		0.0E+00	0.0E+00	0.0E+00	...	0.0E+00
Dose						
Annual						Cumulative
Dose		2.2E-13 + 0.0E+00 + 0.0E+00 + ...	=	2.2E-13		Dose
						Maximum
					2.2E-13	Annual
						Dose Occurred
						In Year 1

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-----  
 GENII Dose Calculation Program  
 (Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48

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-----  
 Release period: 0.0  
 Uptake/exposure period: 1.0  
 Dose commitment period: 1.0  
 Dose units: Rem

Committed Dose Equivalent by Exposure Pathway

Pathway	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes
Leaf Veg	7.2E-17	2.0E-15	5.0E-15	2.3E-14	8.5E-14	4.4E-15	3.9E-16	8.2E-17
Oth. Veg	1.4E-15	3.8E-14	9.6E-14	5.5E-13	1.6E-12	8.5E-14	7.6E-15	1.6E-15
Fruit	4.5E-16	1.2E-14	3.1E-14	1.8E-13	5.3E-13	2.7E-14	2.5E-15	5.1E-16
Cereals	3.7E-17	1.0E-15	2.6E-15	1.5E-14	4.5E-14	2.4E-15	2.1E-16	4.3E-17
Total	1.9E-15	5.3E-14	1.4E-13	7.7E-13	2.3E-12	1.2E-13	1.1E-14	2.2E-15

Pathway	Ovaries	Muscle	Thyroid	Kidneys	Liver
Leaf Veg	2.5E-16	8.6E-17	7.0E-17	1.1E-14	3.3E-18
Oth. Veg	4.8E-15	1.7E-15	1.4E-15	2.2E-13	6.4E-17
Fruit	1.5E-15	5.4E-16	4.4E-16	7.1E-14	2.1E-17
Cereals	1.3E-16	4.5E-17	3.6E-17	5.9E-15	4.7E-18
Total	6.7E-15	2.3E-15	1.9E-15	3.1E-13	9.3E-17

External Dose by Exposure Pathway

Pathway	
Total	0.0E+00

-----  
 GENII Dose Calculation Program  
 (Version 1.485 3-Dec-90)

Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48

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-----  
 Release period: 0.0  
 Uptake/exposure period: 1.0  
 Dose commitment period: 1.0  
 Dose units: Rem

Committed Dose Equivalent by Radionuclide

Radionuclide	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes
U 235	1.0E-15	1.9E-14	4.8E-14	2.7E-13	8.7E-13	5.9E-14	5.6E-15	1.3E-15
TH 231	2.2E-18	3.1E-15	7.4E-15	3.1E-14	5.5E-14	3.4E-17	8.4E-17	8.5E-18
PA 231	1.6E-20	2.4E-18	6.1E-18	3.5E-17	1.1E-16	9.4E-16	7.3E-17	2.2E-20
AC 227	8.6E-23	4.2E-22	1.3E-21	1.1E-20	6.5E-20	2.3E-17	1.8E-18	2.5E-19
TH 227	6.7E-22	8.7E-21	2.1E-20	1.3E-19	4.7E-19	3.6E-19	2.9E-20	7.2E-22
FR 223	2.7E-22	2.9E-22	2.7E-22	2.7E-22	2.7E-22	2.9E-21	3.6E-22	2.7E-22
RA 223	1.8E-19	2.8E-19	3.9E-19	1.4E-18	3.7E-18	1.6E-17	1.2E-18	1.8E-19
U 238	9.2E-16	1.6E-14	4.2E-14	2.4E-13	7.4E-13	5.8E-14	4.7E-15	9.3E-16
TH 234	1.0E-17	1.5E-14	3.8E-14	2.3E-13	6.4E-13	3.0E-16	2.7E-16	3.5E-17
PA 234	3.6E-19	1.9E-17	3.6E-17	7.8E-17	6.3E-17	6.8E-19	2.0E-18	6.1E-19
Total	1.9E-15	5.3E-14	1.4E-13	7.7E-13	2.3E-12	1.2E-13	1.1E-14	2.2E-15

Radionuclide	Ovaries	Muscle	Thyroid	Kidneys	Liver
U 235	4.8E-15	1.3E-15	9.8E-16	1.6E-13	0.0E+00
TH 231	3.4E-16	2.2E-17	1.4E-19	0.0E+00	1.6E-17
PA 231	1.4E-19	2.6E-20	1.5E-20	1.4E-17	8.3E-18
AC 227	2.6E-19	6.3E-23	2.9E-23	0.0E+00	6.2E-18
TH 227	1.5E-21	7.2E-22	6.2E-22	0.0E+00	5.6E-21
FR 223	2.8E-22	2.7E-22	2.7E-22	0.0E+00	0.0E+00
RA 223	1.8E-19	1.8E-19	1.6E-19	0.0E+00	0.0E+00
U 238	1.1E-15	9.2E-16	9.2E-16	1.5E-13	0.0E+00
TH 234	4.3E-16	5.0E-17	4.3E-18	0.0E+00	6.1E-17
PA 234	8.5E-18	1.3E-18	4.6E-20	2.1E-18	1.5E-18
Total	6.7E-15	2.3E-15	1.9E-15	3.1E-13	9.3E-17

---

GENII Dose Calculation Program  
(Version 1.485 3-Dec-90)

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Case title: The ingestion pathway calculation for U-235 and U-238

Executed on: 12/09/94 at 14:49:48

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Release period: 0.0  
Uptake/exposure period: 1.0  
Dose commitment period: 1.0  
Dose units: Rem

Radio- nuclide	Inhalation Effective Dose Equivalent	Ingestion Effective Dose Equivalent	External Dose	Internal Effective Dose Equivalent	Annual Effective Dose Equivalent
U 235	0.0E+00	8.6E-14	0.0E+00	8.6E-14	8.6E-14
TH 231	0.0E+00	5.8E-15	0.0E+00	5.8E-15	5.8E-15
PA 231	0.0E+00	4.7E-17	0.0E+00	4.7E-17	4.7E-17
AC 227	0.0E+00	1.3E-18	0.0E+00	1.3E-18	1.3E-18
TH 227	0.0E+00	5.3E-20	0.0E+00	5.3E-20	5.3E-20
FR 223	0.0E+00	3.5E-22	0.0E+00	3.5E-22	3.5E-22
RA 223	0.0E+00	1.1E-18	0.0E+00	1.1E-18	1.1E-18
U 238	0.0E+00	7.4E-14	0.0E+00	7.4E-14	7.4E-14
TH 234	0.0E+00	5.5E-14	0.0E+00	5.5E-14	5.5E-14
PA 234	0.0E+00	1.5E-17	0.0E+00	1.5E-17	1.5E-17

---



## **APPENDIX C**

### **THE RESRAD OUTPUT**

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Dose Conversion Factor (and Related) Parameter Summary  
 File: DOSFAC.BIN

Menu	Parameter	Current Value	Default	Parameter Name
A-1	Ground external gamma, volume DCF'S, (mrem/yr)/(pCi/cm**3):			
A-1	Ac-227+D , soil density = 1.0 g/cm**3	2.760E+00	2.760E+00	DCF1( 1,1)
A-1	Ac-227+D , soil density = 1.8 g/cm**3	1.520E+00	1.520E+00	DCF1( 1,2)
A-1				
A-1	Pa-231 , soil density = 1.0 g/cm**3	2.210E-01	2.210E-01	DCF1( 2,1)
A-1	Pa-231 , soil density = 1.8 g/cm**3	1.210E-01	1.210E-01	DCF1( 2,2)
A-1				
A-1	Pb-210+D , soil density = 1.0 g/cm**3	4.870E-03	4.870E-03	DCF1( 3,1)
A-1	Pb-210+D , soil density = 1.8 g/cm**3	2.310E-03	2.310E-03	DCF1( 3,2)
A-1				
A-1	Ra-226+D , soil density = 1.0 g/cm**3	1.550E+01	1.550E+01	DCF1( 4,1)
A-1	Ra-226+D , soil density = 1.8 g/cm**3	8.560E+00	8.560E+00	DCF1( 4,2)
A-1				
A-1	Th-230 , soil density = 1.0 g/cm**3	2.110E-03	2.110E-03	DCF1( 5,1)
A-1	Th-230 , soil density = 1.8 g/cm**3	1.030E-03	1.030E-03	DCF1( 5,2)

A-1				
A-1	U-234 , soil density = 1.0 g/cm**3	1.580E-03	1.580E-03	DCF1( 6,1)
A-1	U-234 , soil density = 1.8 g/cm**3	6.970E-04	6.970E-04	DCF1( 6,2)
A-1				
A-1	U-235+D , soil density = 1.0 g/cm**3	8.940E-01	8.940E-01	DCF1( 7,1)
A-1	U-235+D , soil density = 1.8 g/cm**3	4.900E-01	4.900E-01	DCF1( 7,2)
A-1				
A-1	U-238+D , soil density = 1.0 g/cm**3	1.270E-01	1.270E-01	DCF1( 8,1)
A-1	U-238+D , soil density = 1.8 g/cm**3	6.970E-02	6.970E-02	DCF1( 8,2)
A-3	Depth factors, ground external gamma, dimensionless:			
A-3	Ac-227+D , soil density = 1.0 g/cm**3, thickness = .15 m	7.900E-01	7.900E-01	FD( 1,1,1)
A-3	Ac-227+D , soil density = 1.0 g/cm**3, thickness = 0.5 m	9.700E-01	9.700E-01	FD( 1,2,1)
A-3	Ac-227+D , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 1,3,1)
A-3	Ac-227+D , soil density = 1.8 g/cm**3, thickness = .15 m	9.100E-01	9.100E-01	FD( 1,1,2)
A-3	Ac-227+D , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 1,2,2)
A-3	Ac-227+D , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 1,3,2)
A-3				
A-3	Pa-231 , soil density = 1.0 g/cm**3, thickness = .15 m	7.900E-01	7.900E-01	FD( 2,1,1)
A-3	Pa-231 , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 2,2,1)
A-3	Pa-231 , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 2,3,1)
A-3	Pa-231 , soil density = 1.8 g/cm**3, thickness = .15 m	9.200E-01	9.200E-01	FD( 2,1,2)
A-3	Pa-231 , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 2,2,2)
A-3	Pa-231 , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 2,3,2)
A-3				
A-3	Pb-210+D , soil density = 1.0 g/cm**3, thickness = .15 m	8.800E-01	8.800E-01	FD( 3,1,1)
A-3	Pb-210+D , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 3,2,1)
A-3	Pb-210+D , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 3,3,1)
A-3	Pb-210+D , soil density = 1.8 g/cm**3, thickness = .15 m	9.700E-01	9.700E-01	FD( 3,1,2)
A-3	Pb-210+D , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 3,2,2)
A-3	Pb-210+D , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 3,3,2)
A-3				

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Summary : The ingestion pathway calculation for U-235 and U-238

File : RESULT1.DAT

# Dose Conversion Factor (and Related) Parameter Summary (continued)

File: DOSFAC.BIN

0 Menu	Parameter	Current Value	Default	Parameter Name
A-3	Ra-226+D , soil density = 1.0 g/cm**3, thickness = .15 m	6.300E-01	6.300E-01	FD( 4,1,1)
A-3	Ra-226+D , soil density = 1.0 g/cm**3, thickness = 0.5 m	9.200E-01	9.200E-01	FD( 4,2,1)
A-3	Ra-226+D , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 4,3,1)
A-3	Ra-226+D , soil density = 1.8 g/cm**3, thickness = .15 m	8.500E-01	8.500E-01	FD( 4,1,2)

A-3	Ra-226+D , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 4,2,2)
A-3	Ra-226+D , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 4,3,2)
A-3				
A-3	Th-230 , soil density = 1.0 g/cm**3, thickness = .15 m	9.300E-01	9.300E-01	FD( 5,1,1)
A-3	Th-230 , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 5,2,1)
A-3	Th-230 , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 5,3,1)
A-3	Th-230 , soil density = 1.8 g/cm**3, thickness = .15 m	1.000E+00	1.000E+00	FD( 5,1,2)
A-3	Th-230 , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 5,2,2)
A-3	Th-230 , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 5,3,2)
A-3				
A-3	U-234 , soil density = 1.0 g/cm**3, thickness = .15 m	9.000E-01	9.000E-01	FD( 6,1,1)
A-3	U-234 , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 6,2,1)
A-3	U-234 , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 6,3,1)
A-3	U-234 , soil density = 1.8 g/cm**3, thickness = .15 m	1.000E+00	1.000E+00	FD( 6,1,2)
A-3	U-234 , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 6,2,2)
A-3	U-234 , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 6,3,2)
A-3				
A-3	U-235+D , soil density = 1.0 g/cm**3, thickness = .15 m	8.700E-01	8.700E-01	FD( 7,1,1)
A-3	U-235+D , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 7,2,1)
A-3	U-235+D , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 7,3,1)
A-3	U-235+D , soil density = 1.8 g/cm**3, thickness = .15 m	1.000E+00	1.000E+00	FD( 7,1,2)
A-3	U-235+D , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 7,2,2)
A-3	U-235+D , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 7,3,2)
A-3				
A-3	U-238+D , soil density = 1.0 g/cm**3, thickness = .15 m	7.800E-01	7.800E-01	FD( 8,1,1)
A-3	U-238+D , soil density = 1.0 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 8,2,1)
A-3	U-238+D , soil density = 1.0 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 8,3,1)
A-3	U-238+D , soil density = 1.8 g/cm**3, thickness = .15 m	8.800E-01	8.800E-01	FD( 8,1,2)
A-3	U-238+D , soil density = 1.8 g/cm**3, thickness = 0.5 m	1.000E+00	1.000E+00	FD( 8,2,2)
A-3	U-238+D , soil density = 1.8 g/cm**3, thickness = 1.0 m	1.000E+00	1.000E+00	FD( 8,3,2)
B-1	Dose conversion factors for inhalation, mrem/pCi:			
B-1	Ac-227+D	6.700E+00	6.700E+00	DCF2( 1)
B-1	Pa-231	1.300E+00	1.300E+00	DCF2( 2)
B-1	Pb-210+D	2.100E-02	2.100E-02	DCF2( 3)
B-1	Ra-226+D	7.900E-03	7.900E-03	DCF2( 4)
B-1	Th-230	3.200E-01	3.200E-01	DCF2( 5)
B-1	U-234	1.300E-01	1.300E-01	DCF2( 6)
B-1	U-235+D	1.200E-01	1.200E-01	DCF2( 7)
B-1	U-238+D	1.200E-01	1.200E-01	DCF2( 8)
D-1	Dose conversion factors for ingestion, mrem/pCi:			
D-1	Ac-227+D	1.500E-02	1.500E-02	DCF3( 1)
D-1	Pa-231	1.100E-02	1.100E-02	DCF3( 2)
D-1	Pb-210+D	6.700E-03	6.700E-03	DCF3( 3)

D-1 | Ra-226+D | 1.100E-03 | 1.100E-03 | DCF3( 4)  
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 Summary : The ingestion pathway calculation for U-235 and U-238  
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Dose Conversion Factor (and Related) Parameter Summary (continued)  
 File: DOSFAC.BIN

Menu	Parameter	Current Value	Default	Parameter Name
D-1	Th-230	5.300E-04	5.300E-04	DCF3( 5)
D-1	U-234	2.600E-04	2.600E-04	DCF3( 6)
D-1	U-235+D	2.500E-04	2.500E-04	DCF3( 7)
D-1	U-238+D	2.500E-04	2.500E-04	DCF3( 8)
D-34	Food transfer factors:			
D-34	Ac-227+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF( 1,1)
D-34	Ac-227+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	2.000E-05	2.000E-05	RTF( 1,2)
D-34	Ac-227+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	2.000E-05	2.000E-05	RTF( 1,3)
D-34	Pa-231 , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF( 2,1)
D-34	Pa-231 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	5.000E-03	5.000E-03	RTF( 2,2)
D-34	Pa-231 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF( 2,3)
D-34	Pb-210+D , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF( 3,1)
D-34	Pb-210+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	8.000E-04	8.000E-04	RTF( 3,2)
D-34	Pb-210+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	3.000E-04	3.000E-04	RTF( 3,3)
D-34	Ra-226+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF( 4,1)
D-34	Ra-226+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF( 4,2)
D-34	Ra-226+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF( 4,3)
D-34	Th-230 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF( 5,1)
D-34	Th-230 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF( 5,2)
D-34	Th-230 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF( 5,3)
D-34	U-234 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF( 6,1)
D-34	U-234 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF( 6,2)
D-34	U-234 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF( 6,3)
D-34	U-235+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF( 7,1)
D-34	U-235+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF( 7,2)
D-34	U-235+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF( 7,3)
D-34	U-238+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF( 8,1)



D-34	U-238+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF( 8,2)
D-34	U-238+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF( 8,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Ac-227+D , fish	1.500E+01	1.500E+01	BIOFAC( 1,1)
D-5	Ac-227+D , crustacea and mollusks	1.000E+03	1.000E+03	BIOFAC( 1,2)
D-5				
D-5	Pa-231 , fish	1.000E+01	1.000E+01	BIOFAC( 2,1)
D-5	Pa-231 , crustacea and mollusks	1.100E+02	1.100E+02	BIOFAC( 2,2)
D-5				
D-5	Pb-210+D , fish	3.000E+02	3.000E+02	BIOFAC( 3,1)
D-5	Pb-210+D , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC( 3,2)
D-5				
D-5	Ra-226+D , fish	5.000E+01	5.000E+01	BIOFAC( 4,1)
D-5	Ra-226+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC( 4,2)

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Summary : The ingestion pathway calculation for U-235 and U-238

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#### Dose Conversion Factor (and Related) Parameter Summary (continued)

File: DOSFAC.BIN

0 Menu	Parameter	Current Value	Default	Parameter Name
D-5	Th-230 , fish	1.000E+02	1.000E+02	BIOFAC( 5,1)
D-5	Th-230 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC( 5,2)
D-5				
D-5	U-234 , fish	1.000E+01	1.000E+01	BIOFAC( 6,1)
D-5	U-234 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC( 6,2)
D-5				
D-5	U-235+D , fish	1.000E+01	1.000E+01	BIOFAC( 7,1)
D-5	U-235+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC( 7,2)
D-5				
D-5	U-238+D , fish	1.000E+01	1.000E+01	BIOFAC( 8,1)
D-5	U-238+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC( 8,2)

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Summary : The ingestion pathway calculation for U-235 and U-238

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#### Site-Specific Parameter Summary

0 Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)	1.000E+04	1.000E+04	---	AREA

R011	Thickness of contaminated zone (m)	1.500E-01	2.000E+00	---	THICK0
R011	Length parallel to aquifer flow (m)	1.000E+02	1.000E+02	---	LC2PAQ
R011	Basic radiation dose limit (mrem/yr)	3.000E+01	3.000E+01	---	BRDL
R011	Time since placement of material (yr)	0.000E+00	0.000E+00	---	TI
R011	Times for calculations (yr)	1.000E+00	1.000E+00	---	T( 2)
R011	Times for calculations (yr)	5.000E+01	3.000E+00	---	T( 3)
R011	Times for calculations (yr)	not used	1.000E+01	---	T( 4)
R011	Times for calculations (yr)	not used	3.000E+01	---	T( 5)
R011	Times for calculations (yr)	not used	1.000E+02	---	T( 6)
R011	Times for calculations (yr)	not used	3.000E+02	---	T( 7)
R011	Times for calculations (yr)	not used	1.000E+03	---	T( 8)
R011	Times for calculations (yr)	not used	3.000E+03	---	T( 9)
R011	Times for calculations (yr)	not used	1.000E+04	---	T(10)
R012	Initial principal radionuclide (pCi/g): U-235	4.167E-07	0.000E+00	---	S1( 7)
R012	Initial principal radionuclide (pCi/g): U-238	4.167E-07	0.000E+00	---	S1( 8)
R012	Concentration in groundwater (pCi/L): U-235	not used	0.000E+00	---	W1( 7)
R012	Concentration in groundwater (pCi/L): U-238	not used	0.000E+00	---	W1( 8)
R013	Cover depth (m)	1.500E-01	0.000E+00	---	COVER0
R013	Density of cover material (g/cm**3)	not used	1.500E+00	---	DENSCV
R013	Cover depth erosion rate (m/yr)	1.000E-03	1.000E-03	---	VCV
R013	Density of contaminated zone (g/cm**3)	1.600E+00	1.500E+00	---	DENSC2
R013	Contaminated zone erosion rate (m/yr)	1.000E-03	1.000E-03	---	VC2
R013	Contaminated zone total porosity	4.000E-01	4.000E-01	---	TPCZ
R013	Contaminated zone effective porosity	2.000E-01	2.000E-01	---	EPCZ
R013	Contaminated zone hydraulic conductivity (m/yr)	1.000E+01	1.000E+01	---	HCCZ
R013	Contaminated zone b parameter	5.300E+00	5.300E+00	---	BCZ
R013	Humidity in air (g/cm**3)	not used	8.000E+00	---	HUMID
R013	Evapotranspiration coefficient	6.000E-01	5.000E-01	---	EVAPTR
R013	Precipitation (m/yr)	1.000E+00	1.000E+00	---	PRECIP
R013	Irrigation (m/yr)	0.000E+00	2.000E-01	---	RI
R013	Irrigation mode	overhead	overhead	---	IDITCH
R013	Runoff coefficient	2.000E-01	2.000E-01	---	RUNOFF
R013	Watershed area for nearby stream or pond (m**2)	1.000E+06	1.000E+06	---	WAREA
R013	Accuracy for water/soil computations	1.000E-03	1.000E-03	---	EPS
R014	Density of saturated zone (g/cm**3)	1.600E+00	1.500E+00	---	DENSAQ
R014	Saturated zone total porosity	4.000E-01	4.000E-01	---	TPSZ
R014	Saturated zone effective porosity	2.000E-01	2.000E-01	---	EPSZ
R014	Saturated zone hydraulic conductivity (m/yr)	1.000E+02	1.000E+02	---	HCSZ
R014	Saturated zone hydraulic gradient	2.000E-02	2.000E-02	---	HGWT
R014	Saturated zone b parameter	5.300E+00	5.300E+00	---	BSZ
R014	Water table drop rate (m/yr)	1.000E-03	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	1.000E+01	1.000E+01	---	DWIBWT

R014	Model: Nondispersion (ND) or Mass-Balance (MB)	ND	ND	---	MODEL
R014	Well pumping rate (m**3/yr)	1.500E+02	2.500E+02	---	UW
R015	Number of unsaturated zone strata	1	1	---	NS

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Site-Specific Parameter Summary (continued)

0 Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R015	Unsat. zone 1, thickness (m)	2.000E+00	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.800E+00	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	4.200E-01	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.300E-01	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	7.000E+00	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+02	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for U-235				
R016	Contaminated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCC( 7)
R016	Unsaturated zone 1 (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCU( 7,1)
R016	Saturated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCS( 7)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	5.292E-02	ALEACH( 7)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 7)
R016	Distribution coefficients for U-238				
R016	Contaminated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCC( 8)
R016	Unsaturated zone 1 (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCU( 8,1)
R016	Saturated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCHUCS( 8)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	5.292E-02	ALEACH( 8)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 8)
R016	Distribution coefficients for daughter Ac-227				
R016	Contaminated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCHUCC( 1)
R016	Unsaturated zone 1 (cm**3/g)	2.000E+01	2.000E+01	---	DCHUCU( 1,1)
R016	Saturated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCHUCS( 1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	6.603E-02	ALEACH( 1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 1)
R016	Distribution coefficients for daughter Pa-231				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCHUCC( 2)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCHUCU( 2,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCHUCS( 2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.656E-02	ALEACH( 2)

R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 2)
R016	Distribution coefficients for daughter Pb-210				
R016	Contaminated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCC( 3)
R016	Unsaturated zone 1 (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCU( 3,1)
R016	Saturated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCS( 3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.331E-02	ALEACH( 3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 3)
R016	Distribution coefficients for daughter Ra-226				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC( 4)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU( 4,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS( 4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.899E-02	ALEACH( 4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 4)

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Summary : The ingestion pathway calculation for U-235 and U-238

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#### Site-Specific Parameter Summary (continued)

0	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R016	Distribution coefficients for daughter Th-230				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC( 5)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU( 5,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS( 5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.222E-05	ALEACH( 5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 5)
R016	Distribution coefficients for daughter U-234				
R016	Contaminated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCNUCC( 6)
R016	Unsaturated zone 1 (cm**3/g)	2.500E+01	5.000E+01	---	DCNUCU( 6,1)
R016	Saturated zone (cm**3/g)	2.500E+01	5.000E+01	---	DCNUCS( 6)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	5.292E-02	ALEACH( 6)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK( 6)
R017	Inhalation rate (m**3/yr)	not used	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m**3)	not used	2.000E-04	---	MLINH
R017	Dilution length for airborne dust, inhalation (m)	3.000E+00	3.000E+00	---	LM
R017	Exposure duration	3.000E+01	3.000E+01	---	ED
R017	Shielding factor, inhalation	not used	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	not used	7.000E-01	---	SHF1
R017	Fraction of time spent indoors	not used	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	not used	2.500E-01	---	FOTD



R017	Shape factor, external gamma	not used	1.000E+00	---	FS1
R017	Fractions of annular areas within AREA:				
R017	Outer annular radius (m) = $\sqrt{1/x}$	not used	1.000E+00	---	FRAC( 1)
R017	Outer annular radius (m) = $\sqrt{10/x}$	not used	1.000E+00	---	FRAC( 2)
R017	Outer annular radius (m) = $\sqrt{20/x}$	not used	1.000E+00	---	FRAC( 3)
R017	Outer annular radius (m) = $\sqrt{50/x}$	not used	1.000E+00	---	FRAC( 4)
R017	Outer annular radius (m) = $\sqrt{100/x}$	not used	1.000E+00	---	FRAC( 5)
R017	Outer annular radius (m) = $\sqrt{200/x}$	not used	1.000E+00	---	FRAC( 6)
R017	Outer annular radius (m) = $\sqrt{500/x}$	not used	1.000E+00	---	FRAC( 7)
R017	Outer annular radius (m) = $\sqrt{1000/x}$	not used	1.000E+00	---	FRAC( 8)
R017	Outer annular radius (m) = $\sqrt{5000/x}$	not used	1.000E+00	---	FRAC( 9)
R017	Outer annular radius (m) = $\sqrt{1.E+04/x}$	not used	1.000E+00	---	FRAC(10)
R017	Outer annular radius (m) = $\sqrt{1.E+05/x}$	not used	0.000E+00	---	FRAC(11)
R017	Outer annular radius (m) = $\sqrt{1.E+06/x}$	not used	0.000E+00	---	FRAC(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	2.760E+02	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.500E+01	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	not used	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	not used	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	not used	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	not used	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	not used	3.650E+01	---	SOIL
R018	Drinking water intake (L/yr)	not used	5.100E+02	---	DWI
R018	Contamination fraction of drinking water	not used	1.000E+00	---	FDW
R018	Contamination fraction of household water	not used	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	not used	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	1.000E+00	1.000E+00	---	FIKW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9

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Summary : The ingestion pathway calculation for U-235 and U-238

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#### Site-Specific Parameter Summary (continued)

0	Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R018		Contamination fraction of plant food	-1	-1	0.500E+00	FPLANT
R018		Contamination fraction of meat	not used	-1	---	FMEAT
R018		Contamination fraction of milk	not used	-1	---	FMILK
R019		Livestock fodder intake for meat (kg/day)	not used	6.800E+01	---	LF15
R019		Livestock fodder intake for milk (kg/day)	not used	5.500E+01	---	LF16
R019		Livestock water intake for meat (L/day)	not used	5.000E+01	---	LW15
R019		Livestock water intake for milk (L/day)	not used	1.600E+02	---	LW16
R019		Livestock soil intake (kg/day)	not used	5.000E-01	---	LSI



R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	9.000E-01	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	1.000E+00	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	not used	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	not used	1.000E+00	---	FGWIR
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05	---	C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02	---	C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02	---	CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01	---	CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01	---	DHC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07	---	EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10	---	REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01	---	AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01	---	AVFG5
STOR	Storage times of contaminated foodstuffs (days):				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01	---	STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00	---	STOR_T(2)
STOR	Milk	not used	1.000E+00	---	STOR_T(3)
STOR	Meat and poultry	not used	2.000E+01	---	STOR_T(4)
STOR	Fish	not used	7.000E+00	---	STOR_T(5)
STOR	Crustacea and mollusks	not used	7.000E+00	---	STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00	---	STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00	---	STOR_T(8)
STOR	Livestock fodder	not used	4.500E+01	---	STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01	---	FLOOR
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	not used	1.000E-01	---	TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02	---	PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02	---	PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average annual wind speed (m/sec)	not used	2.000E+00	---	WIND
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG

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 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Site-Specific Parameter Summary (continued)

0 Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01	---	EMANA(2)

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	suppressed
2 -- inhalation (w/o radon)	suppressed
3 -- plant ingestion	active
4 -- meat ingestion	suppressed
5 -- milk ingestion	suppressed
6 -- aquatic foods	suppressed
7 -- drinking water	suppressed
8 -- soil ingestion	suppressed
9 -- radon	suppressed

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 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Contaminated Zone Dimensions

Area: 10000.00 square meters  
 Thickness: 0.15 meters  
 Cover Depth: 0.15 meters

Initial Soil Concentrations, pCi/g

U-235 4.167E-07  
 U-238 4.167E-07

0

Total Dose TDOSE(t), mrem/yr

Basic Radiation Dose Limit = 30 mrem/yr

Total Mixture Sum H(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years): 0.000E+00 1.000E+00 5.000E+01  
 TDOSE(t): 1.263E-08 1.200E-08 1.095E-09  
 H(t): 4.210E-10 4.001E-10 3.650E-11

0Maximum TDOSE(t): 1.263E-08 mrem/yr at t = 0.000E+00 years  
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 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)															
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years															
Water Independent Pathways (Inhalation excludes radon)															
0	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil		
0	Radio-														
	Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
	U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.315E-09	0.5000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
	U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.315E-09	0.5000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
	Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.263E-08	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)															
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years															
Water Dependent Pathways															
0	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*		
0	Radio-														
	Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
	U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.315E-09	0.5000
	U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.315E-09	0.5000
	Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.263E-08	1.0000

0\*Sum of all water independent and dependent pathways.

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 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)														
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years														
Water Independent Pathways (Inhalation excludes radon)														
Radio- Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.013E-09	0.5010	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.990E-09	0.4990	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.200E-08	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)  
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

0  
0 Water Dependent Pathways

Radio- Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.013E-09	0.5010
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.990E-09	0.4990
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.200E-08	1.0000

0\*Sum of all water independent and dependent pathways.  
 IRESRAD, Version 5.19 T<sub>1/2</sub> Limit = 0.5 year 12/08/94 17:28 Page 14  
 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)  
As mrem/yr and Fraction of Total Dose At t = 5.000E+01 years

0  
0 Water Independent Pathways (Inhalation excludes radon)

Radio- Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.448E-10	0.5889	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.502E-10	0.4111	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.095E-09	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)  
As mrem/yr and Fraction of Total Dose At t = 5.000E+01 years

0  
0 Water Dependent Pathways

Radio- Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.448E-10	0.5889
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.502E-10	0.4111
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.095E-09	1.0000

0\*Sum of all water independent and dependent pathways.  
 IRESRAD, Version 5.19 T<sub>1/2</sub> Limit = 0.5 year 12/08/94 17:28 Page 15  
 Summary : The ingestion pathway calculation for U-235 and U-238  
 File : RESULT1.DAT

Dose/Source Ratios Summed Over All Pathways



# Parent and Progeny Principal Radionuclide Contributions Indicated

Parent Product Branch DSR(j,t) (mrem/yr)/(pCi/g)  
(i) (j) Fraction t= 0.000E+00 1.000E+00 5.000E+01

U-235	U-235	1.000E+00	1.516E-02	1.438E-02	1.080E-03
U-235	Pa-231	1.000E+00	0.000E+00	5.466E-05	4.153E-04
U-235	Ac-227	1.000E+00	0.000E+00	3.749E-07	5.195E-05
U-235	ΣDSR(j)		1.516E-02	1.443E-02	1.548E-03
U-238	U-238	1.000E+00	1.516E-02	1.438E-02	1.080E-03
U-238	U-234	1.000E+00	0.000E+00	4.384E-08	1.591E-07
U-238	Th-230	1.000E+00	0.000E+00	1.869E-13	8.778E-11
U-238	Ra-226	1.000E+00	0.000E+00	1.907E-15	5.839E-11
U-238	Pb-210	1.000E+00	0.000E+00	3.557E-17	2.968E-11
U-238	ΣDSR(j)		1.516E-02	1.438E-02	1.081E-03

Branch Fraction is the cumulative factor for the j'th principal radionuclide daughter: CUMBRF(j) = BRF(1)\*BRF(2)\* ... BRF(j).  
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

0

Single Radionuclide Soil Guidelines G(i,t) in pCi/g

Basic Radiation Dose Limit = 30 mrem/yr

Radionuclide

(i)	t= 0.000E+00	1.000E+00	5.000E+01
U-235	1.979E+03	2.079E+03	1.938E+04
U-238	1.979E+03	2.087E+03	2.776E+04

0

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)  
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g  
at tmin = time of minimum single radionuclide soil guideline  
and at tmax = time of maximum total dose = 0.000E+00 years

Radionuclide	Initial	tmin	DSR(i,tmin)	G(i,tmin)	DSR(i,tmax)	G(i,tmax)
(i)	pCi/g	(years)		(pCi/g)		(pCi/g)
U-235	4.167E-07	0.000E+00	1.516E-02	1.979E+03	1.516E-02	1.979E+03
U-238	4.167E-07	0.000E+00	1.516E-02	1.979E+03	1.516E-02	1.979E+03

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Summary : The ingestion pathway calculation for U-235 and U-238

File : RESULT1.DAT

Individual Nuclide Dose Summed Over All Pathways  
Parent Nuclide and Branch Fraction Indicated  
Radionuclide Parent BRF(i) DOSE(j,t), mrem/yr

(j)	(i)		t= 0.000E+00 1.000E+00 5.000E+01		
U-235	U-235	1.000E+00	6.315E-09	5.990E-09	4.502E-10
OPa-231	U-235	1.000E+00	0.000E+00	2.278E-11	1.730E-10
0Ac-227	U-235	1.000E+00	0.000E+00	1.562E-13	2.165E-11
OU-238	U-238	1.000E+00	6.315E-09	5.990E-09	4.502E-10
OU-234	U-238	1.000E+00	0.000E+00	1.827E-14	6.627E-14
0Th-230	U-238	1.000E+00	0.000E+00	7.788E-20	3.657E-17
ORa-226	U-238	1.000E+00	0.000E+00	7.947E-22	2.433E-17
OPb-210	U-238	1.000E+00	0.000E+00	1.482E-23	1.237E-17

BRF(i) is the branch fraction of the parent nuclide.

Individual Nuclide Soil Concentration					
Parent Nuclide and Branch Fraction Indicated					
ONuclide	Parent	BRF(i)	S(j,t), pCi/g		
(j)	(i)		t= 0.000E+00 1.000E+00 5.000E+01		
U-235	U-235	1.000E+00	4.167E-07	3.952E-07	2.955E-08
OPa-231	U-235	1.000E+00	0.000E+00	8.462E-12	6.478E-11
0Ac-227	U-235	1.000E+00	0.000E+00	1.324E-13	2.341E-11
OU-238	U-238	1.000E+00	4.167E-07	3.952E-07	2.955E-08
OU-234	U-238	1.000E+00	0.000E+00	1.118E-12	4.180E-12
0Th-230	U-238	1.000E+00	0.000E+00	5.122E-18	2.807E-15
ORa-226	U-238	1.000E+00	0.000E+00	7.426E-22	2.279E-17
OPb-210	U-238	1.000E+00	0.000E+00	5.755E-24	7.507E-18

BRF(i) is the branch fraction of the parent nuclide.



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Part IV: Concentration of Radionuclides

Concentration of radionuclides in different media

Time= 0.000E+00 .....	2
Time= 1.000E+00 .....	3
Time= 5.000E+01 .....	4

Concentration of radionuclides in different media  
 at t = 0.000E+00 years\*

Radio- Nuclide	Contamina- ted Zone	Surface Soil	Air Par- ticate	Well Water	Surface Water	Nonleafy Vegetable	Leafy Vegetable	Fodder	Meat	Milk	Fish	Crustacea
	pCi/g	pCi/g	pCi/m**3	pCi/l	pCi/l	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/l	pCi/kg	pCi/kg
Ac-227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa-231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-235	4.17E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-07	1.74E-07	1.74E-07	4.01E-09	5.73E-09	0.00E+00	0.00E+00
U-238	4.17E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-07	1.74E-07	1.74E-07	4.01E-09	5.73E-09	0.00E+00	0.00E+00

\*For all foodstuff media, concentrations are adjusted for storage time before use.

Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.

The Surface soil is the top layer of soil within the user specified mixing zone/depth.

Concentration of radionuclides in different media  
 at t = 1.000E+00 years\*

Radio-Nuclide	Contamina- ted Zone	Surface Soil	Air Par- ticulate	Well Water	Surface Water	Nonleafy Vegetable	Leafy Vegetable	Fodder	Meat	Milk	Fish	Crustacea
	pCi/g	pCi/g	pCi/m**3	pCi/l	pCi/l	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/l	pCi/kg	pCi/kg
Ac-227	1.32E-13	8.82E-16	1.71E-19	0.00E+00	0.00E+00	7.24E-14	5.64E-14	1.11E-13	9.03E-15	1.31E-16	0.00E+00	0.00E+00
Pa-231	8.46E-12	5.64E-14	1.10E-17	0.00E+00	0.00E+00	1.42E-11	1.41E-11	1.45E-11	5.09E-12	4.50E-15	0.00E+00	0.00E+00
Pb-210	5.76E-24	3.84E-26	7.45E-30	0.00E+00	0.00E+00	1.55E-23	1.00E-23	2.86E-23	2.15E-24	5.01E-25	0.00E+00	0.00E+00
Ra-226	7.43E-22	4.95E-24	9.61E-28	0.00E+00	0.00E+00	4.97E-21	4.95E-21	5.01E-21	3.43E-22	2.78E-22	0.00E+00	0.00E+00
Th-230	5.12E-18	3.41E-20	6.63E-24	0.00E+00	0.00E+00	1.02E-18	8.66E-19	1.40E-18	1.80E-20	9.54E-22	0.00E+00	0.00E+00
U-234	1.12E-12	7.45E-15	1.45E-18	0.00E+00	0.00E+00	4.84E-13	4.67E-13	5.23E-13	1.40E-14	1.96E-14	0.00E+00	0.00E+00
U-235	3.95E-07	2.63E-09	5.12E-13	0.00E+00	0.00E+00	1.65E-07	1.65E-07	1.65E-07	4.26E-09	6.23E-09	0.00E+00	0.00E+00
U-238	3.95E-07	2.63E-09	5.12E-13	0.00E+00	0.00E+00	1.65E-07	1.65E-07	1.65E-07	4.26E-09	6.23E-09	0.00E+00	0.00E+00

\*For all foodstuff media, concentrations are adjusted for storage time before use.

Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.

The Surface soil is the top layer of soil within the user specified mixing zone/depth.

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Concent : The ingestion pathway calculation for U-235 and U-238

File : RESULT1.DAT

Concentration of radionuclides in different media  
at t = 5.000E+01 years\*

Radio-Nuclide	Contamina- ted Zone	Surface Soil	Air Par- ticulate	Well Water	Surface Water	Nonleafy Vegetable	Leafy Vegetable	Fodder	Meat	Milk	Fish	Crustacea
	pCi/g	pCi/g	pCi/m**3	pCi/l	pCi/l	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/l	pCi/kg	pCi/kg
Ac-227	2.34E-11	7.80E-12	1.52E-15	0.00E+00	0.00E+00	9.92E-12	9.96E-12	1.04E-11	2.51E-13	8.94E-14	0.00E+00	0.00E+00
Pa-231	6.48E-11	2.16E-11	4.19E-15	0.00E+00	0.00E+00	1.08E-10	1.09E-10	1.09E-10	9.09E-11	8.40E-14	0.00E+00	0.00E+00
Pb-210	7.51E-18	2.50E-18	4.86E-22	0.00E+00	0.00E+00	1.27E-17	1.26E-17	1.31E-17	1.74E-18	5.93E-19	0.00E+00	0.00E+00
Ra-226	2.28E-17	7.60E-18	1.48E-21	0.00E+00	0.00E+00	1.52E-16	1.52E-16	1.52E-16	1.41E-17	1.22E-17	0.00E+00	0.00E+00
Th-230	2.81E-15	9.36E-16	1.82E-19	0.00E+00	0.00E+00	4.73E-16	4.92E-16	4.96E-16	5.03E-17	2.49E-18	0.00E+00	0.00E+00
U-234	4.18E-12	1.39E-12	2.71E-16	0.00E+00	0.00E+00	1.75E-12	1.78E-12	1.78E-12	2.78E-13	4.77E-13	0.00E+00	0.00E+00
U-235	2.96E-08	9.85E-09	1.91E-12	0.00E+00	0.00E+00	1.24E-08	1.26E-08	1.26E-08	1.97E-09	3.37E-09	0.00E+00	0.00E+00
U-238	2.96E-08	9.85E-09	1.91E-12	0.00E+00	0.00E+00	1.24E-08	1.26E-08	1.26E-08	1.97E-09	3.37E-09	0.00E+00	0.00E+00

\*For all foodstuff media, concentrations are adjusted for storage time before use.

Concentrations in the media occurring in pathways that are suppressed are calculated using the current input parameters, i.e. using parameters appearing in the input screen when the pathways are active.

The Surface soil is the top layer of soil within the user specified mixing zone/depth.  
0C:\RES519\RESMAIN3.EXEexecution time = 22.68 seconds